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TECHNICAL NOTE

D-190

EXPLORATORY INVESTIGATION OF SEVERAL COATED AND UNCOATED
METAL, REFRACTORY, AND GRAPHITE MODELS IN A
3,800° F STAGNATION TEMPERATURE AIR JET

By Otto F. Trout, Jr.

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Langley Field, Va.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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STAGNATION TEMPERATURE AIR JET (NASA) 76 p

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EXPLORATORY INVESTIGATION OF SEVERAL COATED AND UNCOATED
METAL, REFRACTORY, AND GRAPHITE MODELS IN A
3,800° F STAGNATION TEMPERATURE AIR JET

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SUMMARY

An exploratory investigation was conducted on several coated and uncoated metal, graphite, and refractory materials models to determine their reaction in a high-velocity hot airstream having stagnation temperature of approximately 3,800° F for periods of time up to 60 seconds. Tests on the molybdenum models indicate that unprotected molybdenum oxidizes rapidly, whereas the metal protected by various coatings successfully resisted rapid oxidation for short periods of time. Some other coatings on molybdenum were not successful. Tests on various grades of graphite produced rapid oxidation when the material was heated to a high temperature. Siliconized graphite and silicon carbide bonded graphite exhibited better oxidation resistance than plain graphite. Refractory models of silicon carbide, zirconium boride, and siliconized boron showed little change during the tests. A description of the models and the results of the tests performed on them are presented in the present paper.

INTRODUCTION

The search for materials to withstand the heating of increased speeds of flight in the atmosphere has resulted in the demand for increased research on existing materials. Even in the range of 2,000° to 3,000° F little is known of the reaction of materials due to aerodynamic heating. There is a demand for super materials to withstand temperatures of several thousand degrees Fahrenheit in the atmosphere; however, at the present time no scientific breakthrough has occurred in the study of basic properties of matter or solid-state physics for developing such super materials. For the present, technological advances in materials will consist of improvements of existing known substances and combinations thereof.

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High melting point metals such as tungsten, tantalum, niobium, and molybdenum have the disadvantage that they oxidize rapidly in air at temperatures below their melting points (refs. 1, 2, and 3). In general, these oxides are volatile or melt at temperatures below the melting point of the basic metal and are generally porous, offering little protection from oxidation. The usefulness of these metals for high-temperature applications in air depends upon the development of coatings or platings which will protect them from oxidation and ignition.

In this series of tests, molybdenum was tested in a hot air jet with platings of chromium and nickel and coatings of molybdenum disilicide, aluminum oxide, zirconium oxide, and nickel aluminide. A model of tungsten was tested with a nickel chromium plating.

Since more information is needed about the lesser known ceramics at high temperatures in air, models of zirconium boride, titanium boride, and siliconized boron were tested. Silicon carbide, the properties of which are well known, was also tested. Carbon is of interest because of its high sublimation temperature and its high heat of sublimation. Because carbon oxidizes rapidly at higher temperatures in air, several grades of graphite were tested to determine relative oxidation resistance. Protective coatings of silicon dioxide, silicon carbide bonded graphite, zirconia, alumina, chrome plate, and platinum plate on graphite were also tested to determine their ability to protect carbon from oxidation.

Very little information is presently available on the reaction of materials at higher temperatures under dynamic conditions in air. The purpose of present tests was to make a qualitative determination of the ability of several materials to withstand heating in a high-temperature, high-velocity airstream. Each model was tested for approximately 60 seconds or until it was damaged in a Mach number 2.0 airstream having a stagnation temperature of approximately $3,800^{\circ}\text{F}$ and stagnation pressure of 105 psia.

The results of the tests of several coated and uncoated molybdenum, carbon, and ceramic models are presented in the present paper.

TESTS AND METHODS

Figure 1 presents diagrams of model configurations 1 and 2. All the models used in this series of tests were configuration 1 except the models of zirconium boride and siliconized boron which are represented by configuration 2. Figure 2 presents a photograph of the assembly of configuration 1 on the adapter and sting for mounting the model in the jet. Each model was tested in the laboratory-scale ceramic-heated air jet (fig. 3) in a Mach number 2.0 air jet at an average stagnation

temperature of about 3,800° F and 105 psia stagnation pressure for approximately 60 seconds or until the model failed. A more detailed description of the test facility is provided in references 4 and 5.

Photographs of each of the models were taken before and after each test. High-speed motion pictures of each test were made to observe the reaction of the models in the hot airstream.

A description of the materials from which each of the models was constructed is provided in table I. All of the molybdenum models were constructed of a molybdenum alloy containing 0.5 percent titanium.

RESULTS AND DISCUSSION

The results of the present tests are tabulated in table I and photographs of the model and tests are presented in figures 4 to 28.

From the present series of tests it is evident that it is possible to protect molybdenum from oxidation for short periods of time by various coatings - such as, chrome plate, Chromalloy W-2, nickel aluminide, and flame-sprayed molybdenum disilicide. Small imperfections in the coating did not appear to cause rapid failure as evidenced by the molybdenum model with a small hole drilled through the coating for one of the tests. Further investigation of those coatings which failed during the tests, such as chrome nickel plate, flame-sprayed zirconia molybdenum laminate and flame-sprayed alumina molybdenum laminate, and unprotected molybdenum, was not made. Some of the factors which may cause failure of a coating can be difference in thermal expansion between the coating and base material, gaseous diffusion through the coating, the reaction between the coating and base material, and spalling of the coating.

Of the ceramic models tested, only the titanium boride model failed under test conditions, and this is not conclusive since the model was slightly cracked before the test. Refractory models of silicon carbide, zirconium boride, and siliconized boron withstood the heating during the tests. Even though these ceramics withstood high temperatures, it would be necessary to test them in larger sections for thermal shock in order to determine their usefulness.

Tests on the graphite models indicated that graphite oxidized rapidly when heated in a hot air jet for the different grades tested. Graphite can be protected from oxidation by various means, some of which were tried in the present series of tests. Silicon carbide bonded graphite appeared to have much better oxidation resistance than ordinary graphite. Siliconized graphite also had good oxidation resistance. Tests on the other coatings on graphite produced failure of the coatings

in some manner, although each showed some improvement over plain graphite. Improvements of coatings could probably be made to protect carbon from oxidation for longer periods of time.

The present series of tests indicate that presently known materials can be used to withstand high-velocity high-temperature air at the conditions of the tests.

CONCLUSIONS

Tests of coated and uncoated molybdenum, tungsten, refractory materials, and graphite models in a Mach number 2.0 air jet having a stagnation temperature of 3,800° F produced the following results for test durations of approximately 60 seconds:

1. Under the test conditions models of molybdenum were successfully protected against oxidation by chrome plate, Chromalloy W-2, nickel aluminide, and flame-sprayed molybdenum disilicide.
2. Models of molybdenum protected by chrome nickel plate, flame-sprayed zirconia molybdenum laminate, and flame-sprayed alumina molybdenum laminate, and unprotected molybdenum failed during the test.
3. Several grades of graphite were tested, all of which oxidized rapidly when heated in the hot air jet. Siliconized graphite and silicon carbide bonded graphite were superior to graphite in oxidation resistance.
4. Refractory models of silicon carbide, zirconium boride, and siliconized boron withstood the heating during the tests.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., September 10, 1959.

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REFERENCES

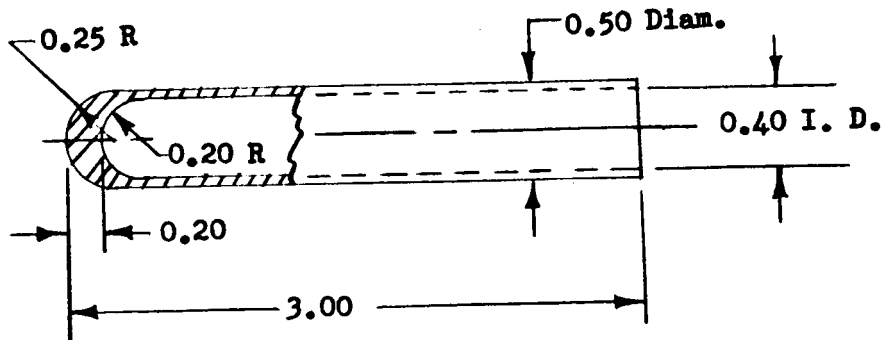
1. Hampel, Clifford A., ed.: Rare Metals Handbook. Reinhold Pub. Corp. (New York), 1954.
2. Harwood, Julius J., ed.: The Metal Molybdenum. A.S.M. (Cleveland, Ohio), c.1958.
3. Grobecker, D. W., ed.: Metals for Supersonic Aircraft and Missiles. A.S.M. (Cleveland, Ohio), c.1958.
4. Fields, E. M., Hopko, Russell N., Swain, Robert L., and Trout, Otto F., Jr.: Behavior of Some Materials and Shapes in Supersonic Free Jets at Stagnation Temperatures up to $4,210^{\circ}$ F, and a Description of the Jets. NACA RM L57K26, 1958.
5. Hopko, Russell N., and Trout Otto F., Jr.: Exploratory Tests of the Behavior of Several Materials in a Supersonic Air Jet at $4,000^{\circ}$ F. NACA RM L57E24, 1957.

TABLE I.- DESCRIPTION OF MODELS AND TESTS

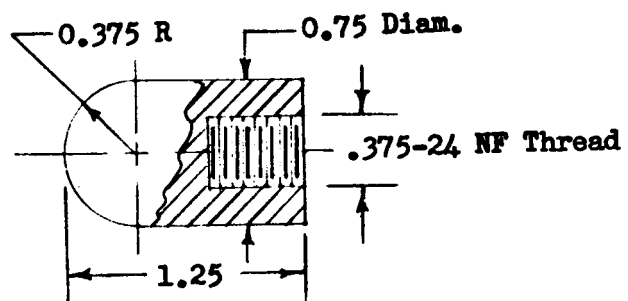
Description of material	Model configuration	Photographs of model	Figure	Duration of test, sec	Reaction of model during test	Remarks
Molybdenum, unprotected	1	Before and after test During test	4(a) 4(b)	26	Oxidation rate increased with surface temperature, ignition occurred at about 26 sec	
Molybdenum, electroplated with 3 mils of nickel undercoat and 2 mils chromium electroplated on surface	1	Before and after test During test	5(a) 5(b)	59	Nickel and chrome plate failed progressively during test	Exposed molybdenum did not ignite during test
Molybdenum, coated with Chromalloy W-2	1	Before and after test During test	6(a) 6(b)	59	No failure occurred, surface blackened, slight flow of material on front face	
Same as previous test except 1/32-inch hole drilled 1/32 inch deep on center of front face of model	1	During test	6(c)	60	Slight oxidation of material in drilled hole, coating intact at end of test	Same appearance as model in previous test
Molybdenum, electroplated with 4 mils of chromium	1	Before and after test During test	7(a) 7(b)	60	No failure of plating, surface blackened	Only 40 sec of film taken during test
Molybdenum, coated with 5 mils of nickel aluminate	1	Before and after test During test	8(a) 8(b)	58	No failure occurred, surface was blistered and darkened after test	
Molybdenum, coated with flame-sprayed molybdenum disilicide	1	Before and after test During test	9(a) 9(b)	57	Model remained intact, surface darkened	
Molybdenum, coated with alternate layers of flame-sprayed zirconia and molybdenum, 3 layers of zirconia and 3 layers of molybdenum	1	Before and after test During test	10(a) 10(b)	58	Coatings failed progressively	Very little mass loss occurred on the exposed molybdenum surface
Molybdenum, coated with alternate layers of flame-sprayed alumina and molybdenum, 3 layers of molybdenum and 3 layers of alumina	1	Before and after test During test	11(a) 11(b)		Coating failed progressively	
Tungsten, electroplated with 3 mils of nickel and 2 mils chromium electrodeposited on surface	1	Before and after test During test	12(a) 12(b)	12	Failure of plating produced rapid oxidation of tungsten	
Phosphate-bonded alumina chromia ceramic reinforced with spirally wrapped molybdenum wire	1	Before and after test During test	13(a) 13(b)	60	Surface spalled causing partial damage	
Hot pressed zirconium boride	2	Before and after test During test	14(a) 14(b)	60	Model intact after test	
Hot pressed siliconized boron machined after pressing	2	Before and after test During test	15(a) 15(b)	60	Some spalling of unfinished wall	
Hot pressed titanium boride machined after pressing	1	Before test During test	16(a) 16(b)	59	Model broke in many pieces at 59 sec	
KT silicon carbide	1	Before and after test During test	17(a) 17(b)	60	Model remained intact, some oxidation of front face	

TABLE I.- DESCRIPTION OF MODELS AND TESTS - Concluded

Description of material	Model configuration	Photographs of model	Figure	Duration of test, sec	Reaction of model during test	Remarks
Speer grade 8334 graphite	1	Before test During test Repeat test	18(a) 18(b) 18(c)	23 Repeat 26	Graphite oxidized rapidly, model broke into many small pieces	
Speer grade 3499 graphite	1	Before test During test Repeat test with new model	19(a) 19(b) 19(c)	21 Repeat 21	Glowed extremely bright, model broke into many small pieces	
Speer grade 8204 graphite	1	Before test During test	20(a) 20(b)	32	Glowed extremely bright, model broke into many small pieces	
Great Lakes type R graphite	1	Before test During test Repeat test with new model	21(a) 21(b) 21(c)	22.5 Repeat 27	Glowed very bright before breaking into many small pieces	
ATJ graphite	1	Before test During test Repeat test	22(a) 22(b) 22(c)	16.5 Repeat 16.5	Glowed very bright before breaking into many small pieces	
Siliconized ATJ graphite prepared by vapor depositing silicon on graphite	1	Before and after test During test Repeat test with new model	23(a) 23(c) 23(b) 23(d)	60 Repeat 60	Very little change, repeat test showed more damage	Silicon oxide appears to increase oxidation resistance of graphite
Silicon carbide bonded graphite	1	Before test After test During test	24(a) 24(b) 24(c)	60	Some oxide on front surface	
ATJ graphite electroplated with chromium	1	Before test	25(a) 25(b)	23.5	Model broke up	
ATJ graphite, electroplated with chromium undercoat, platinum electrodeposited on surface	1	Before and after test During test	26(a) 26(b)	58	Model partially failed	Better oxidation resistance than graphite
ATJ graphite, coated with alternate layers of flame-sprayed zirconia and molybdenum, 3 coats molybdenum and 2 layers of zirconia	1	During test	27	33	Failure was progressive	
ATJ graphite, coated with alternate layers of flame-sprayed alumina and molybdenum, 3 layers of molybdenum and 2 layers of alumina	1	Before test During test	28(a) 28(b)	32	Failure was progressive	



Configuration 1



Configuration 2

Figure 1.- Diagrams of the models. All dimensions are in inches.

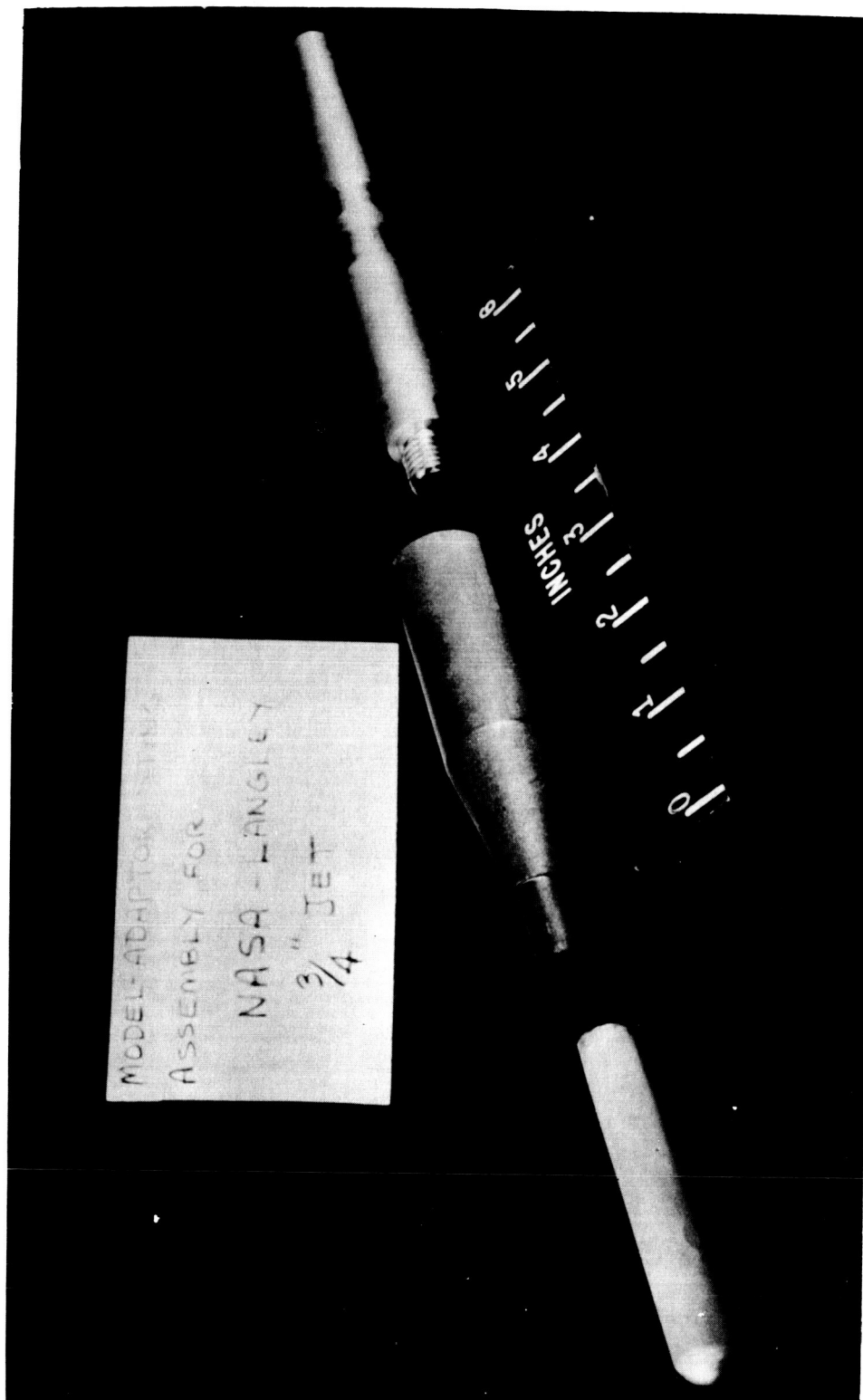


Figure 2.- Photograph of model assembly. L-58-694a

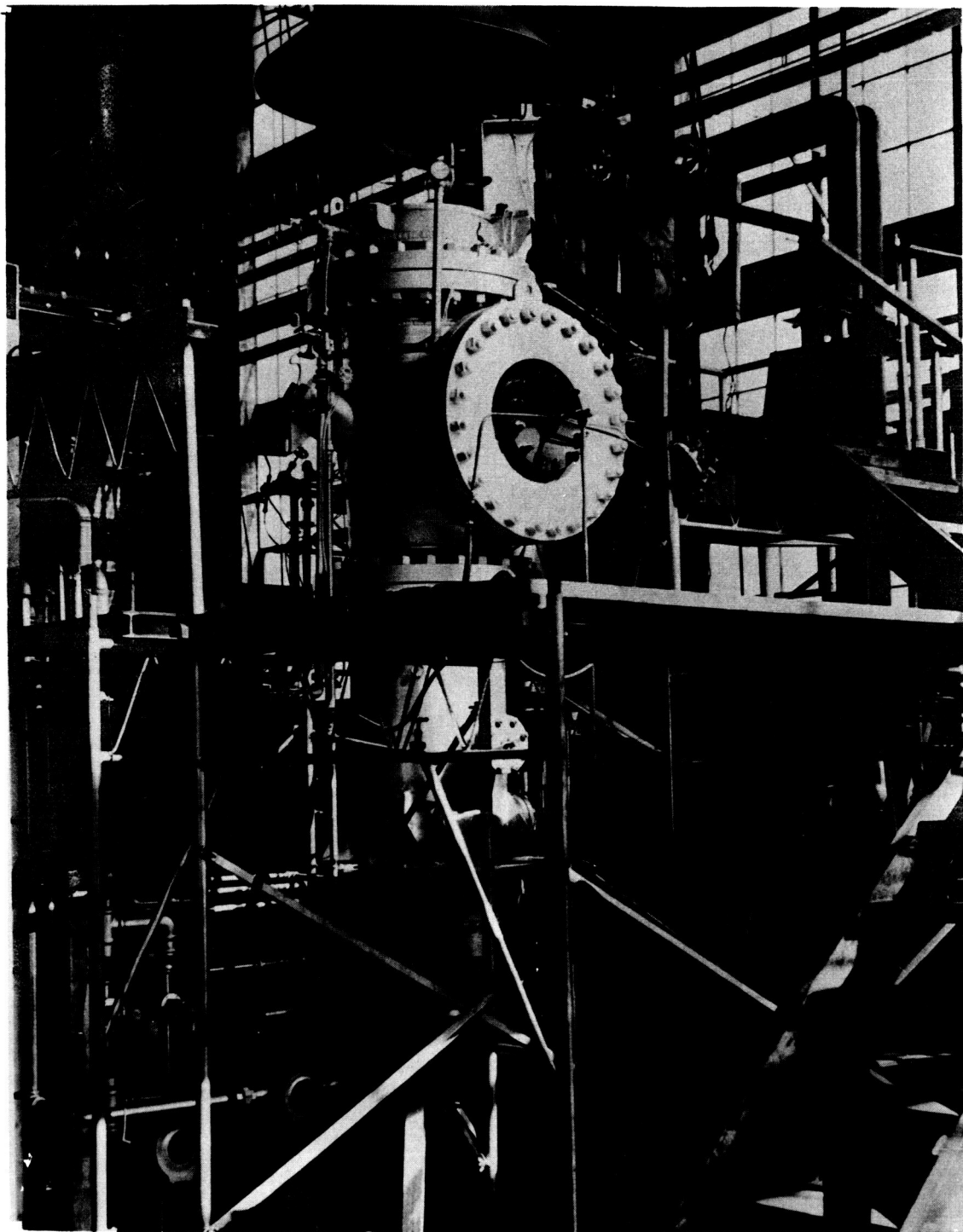
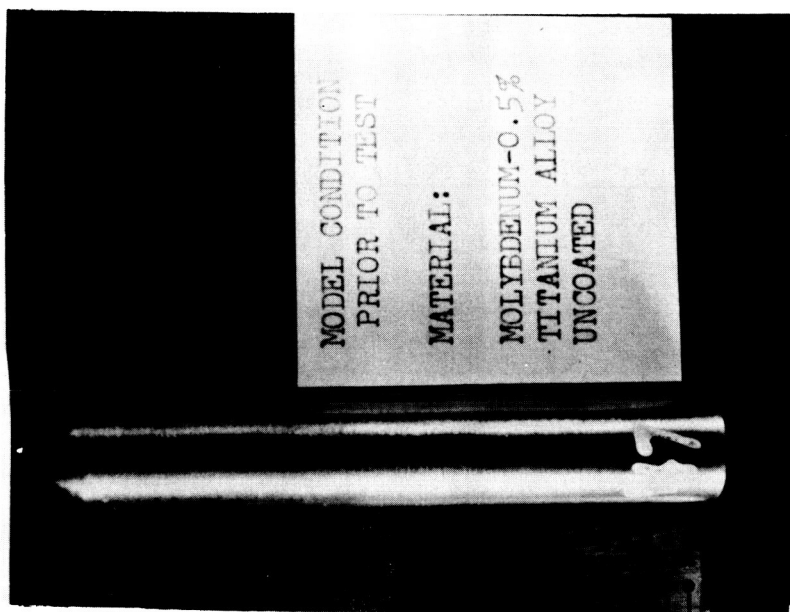
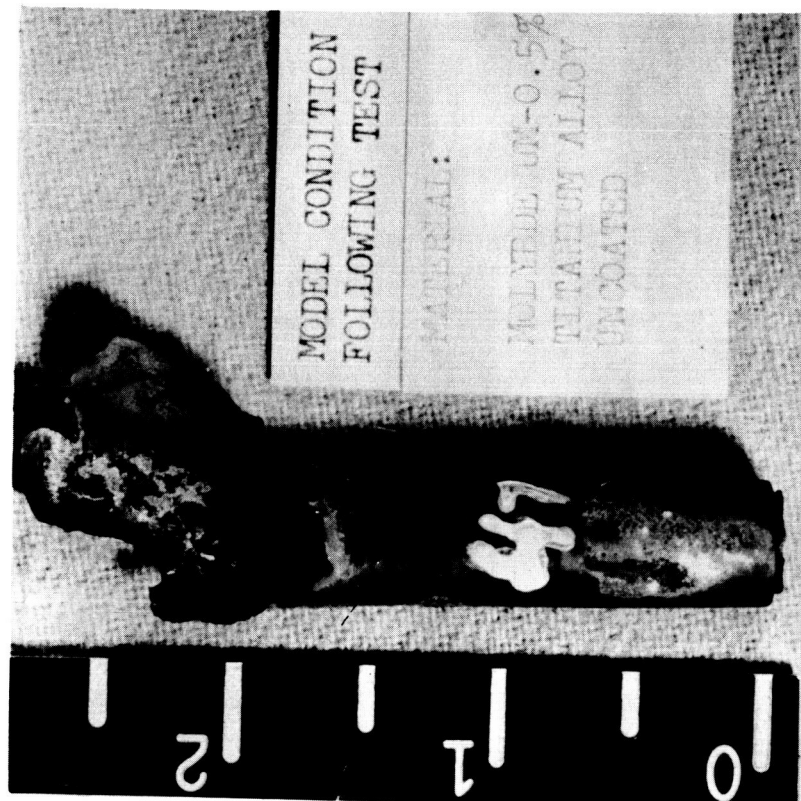
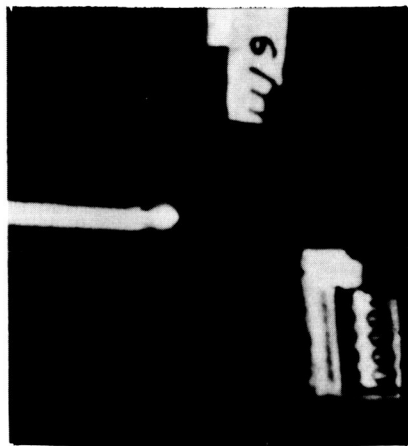


Figure 3.- Photograph of test facility. L-59-2707

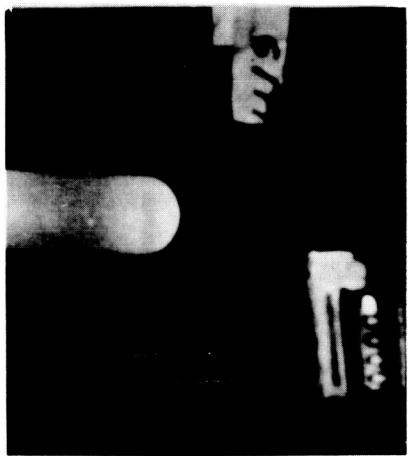


(a) Before and after the test. L-59-6400

Figure 4.- Unprotected molybdenum model.



0 seconds



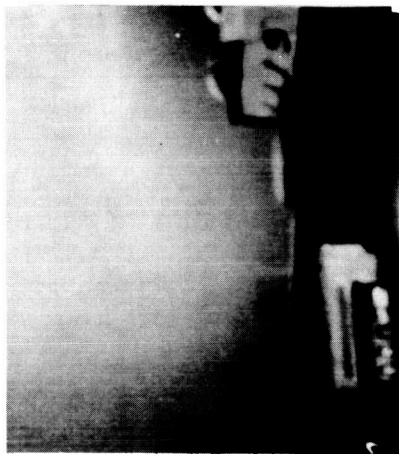
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14 seconds



21 seconds

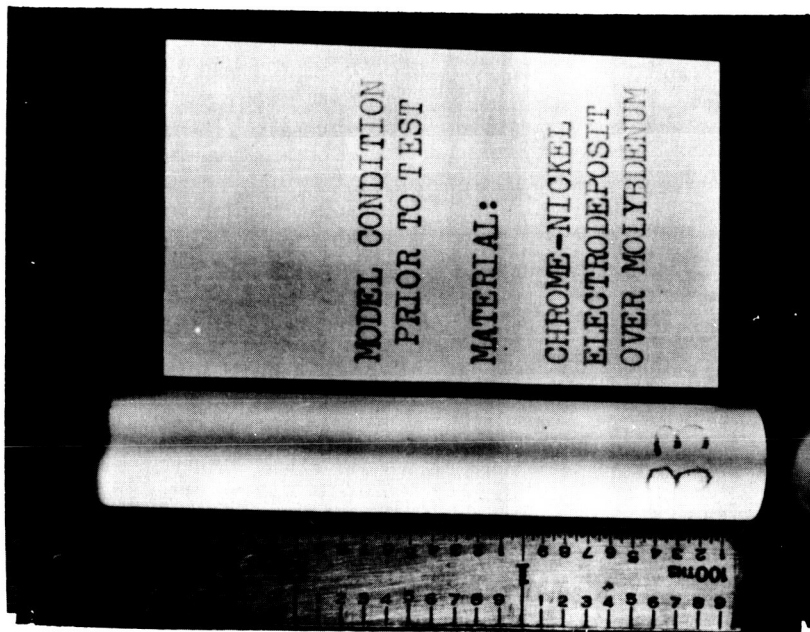
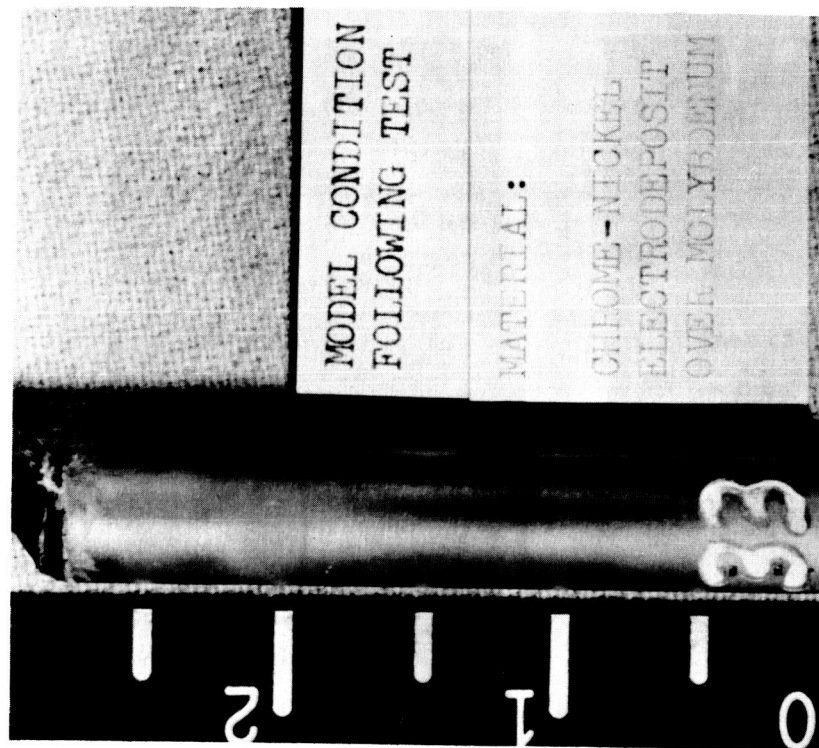


26 seconds

(b) During the test.

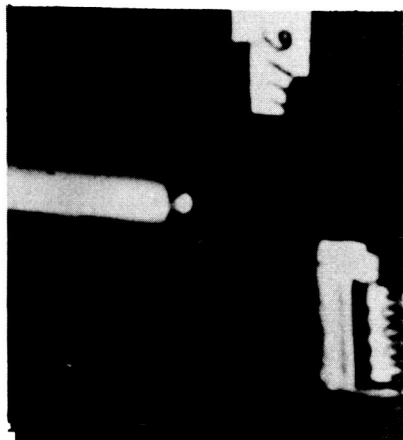
Figure 4.- Concluded.

L-59-6401

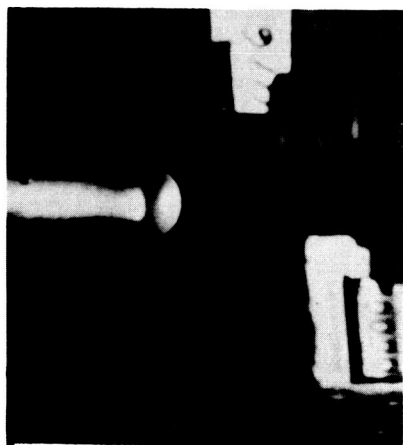


(a) Before and after the test. L-59-6402

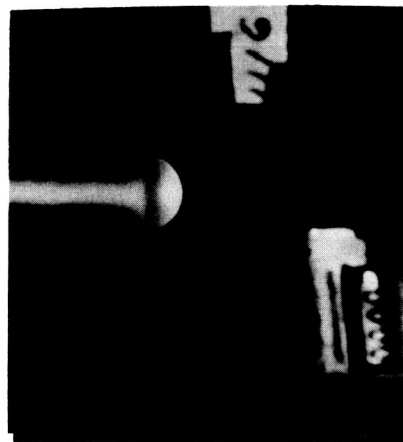
Figure 5.- Nickel chromium electroplated molybdenum model.



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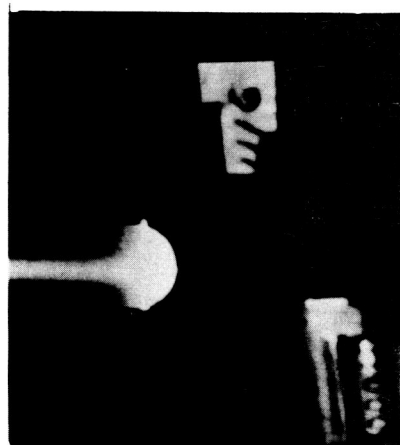
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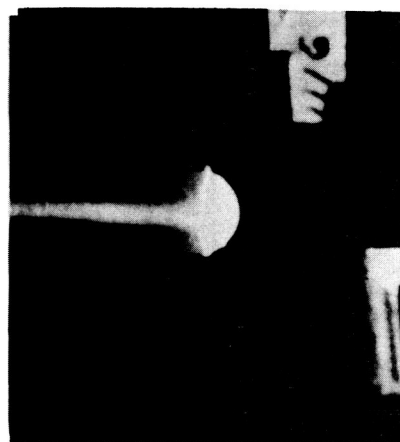
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12 seconds



16 seconds



23 seconds

(b) During the test.

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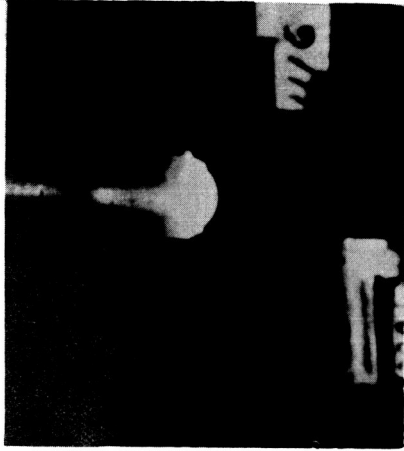
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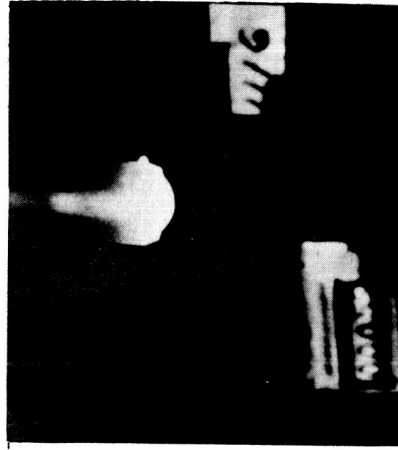
39 seconds



48 seconds



56 seconds

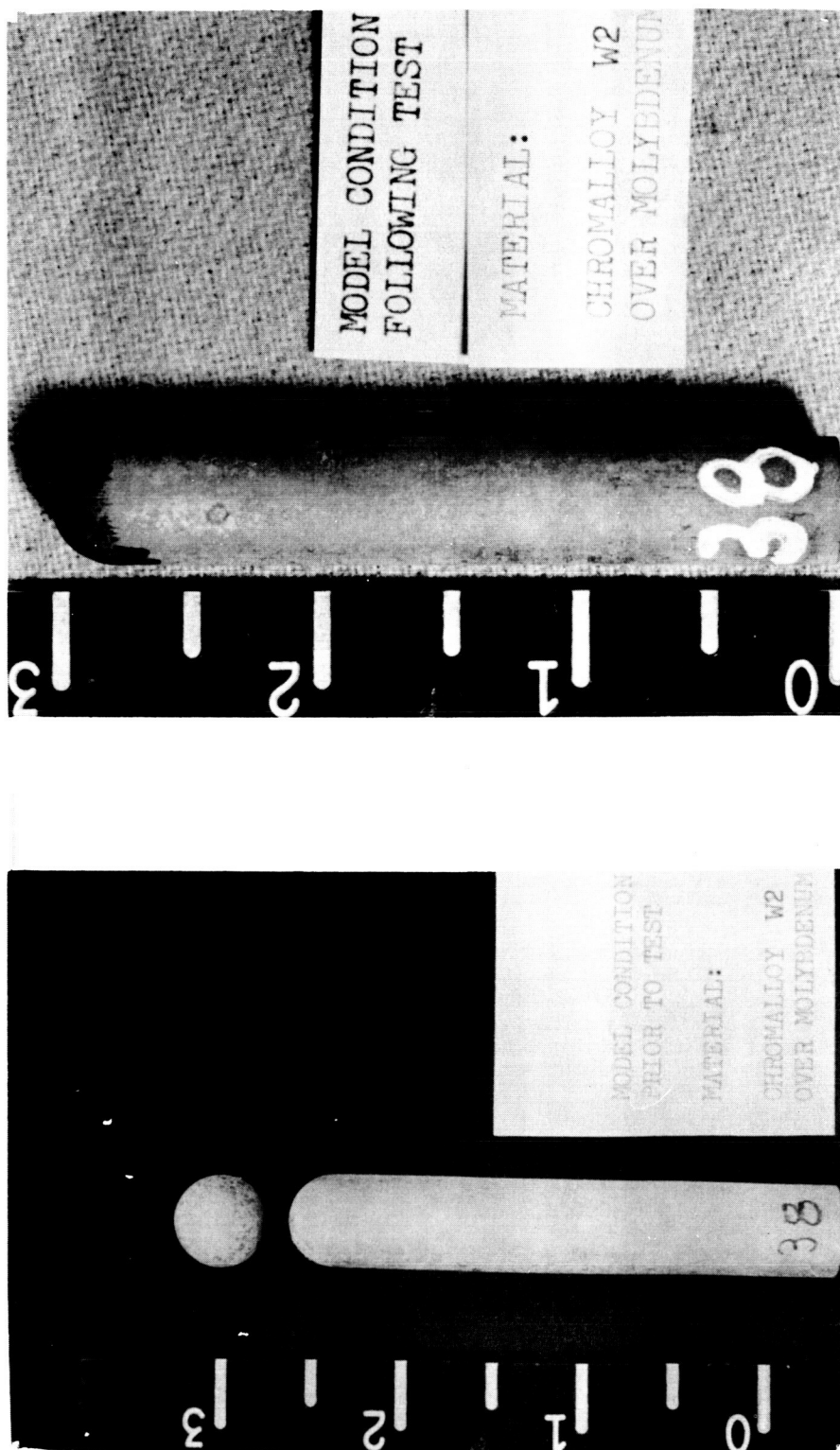


59 seconds

(b) Concluded.

L-59-6404

Figure 5.- Concluded.

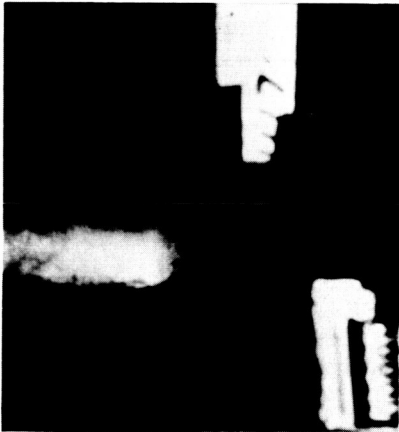


(a) Before and after the test.

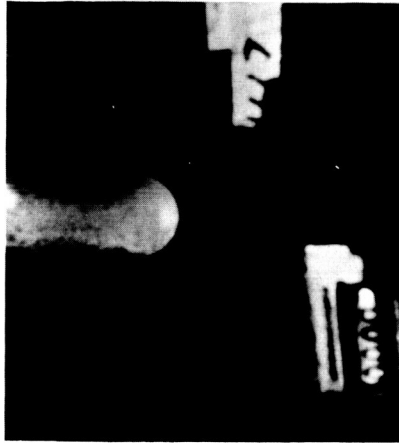
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Figure 6.- Chromalloy W-2 coated molybdenum model.

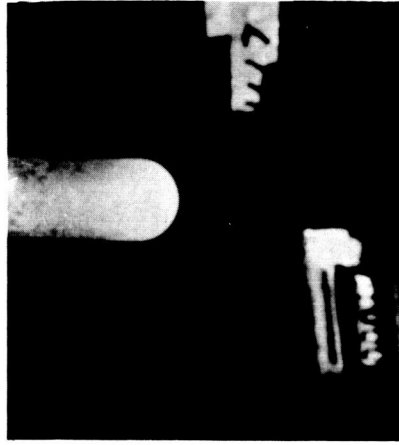
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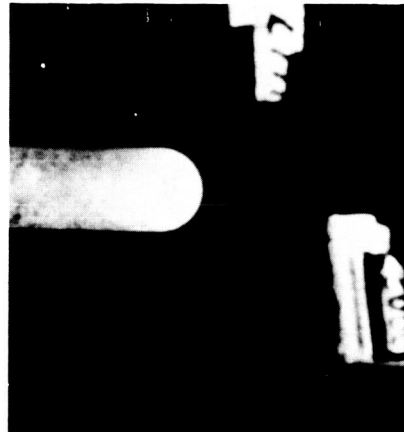
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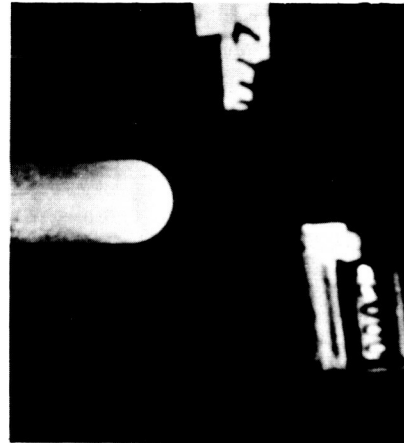
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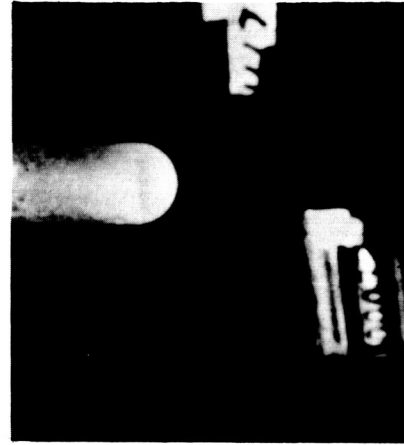
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21 seconds



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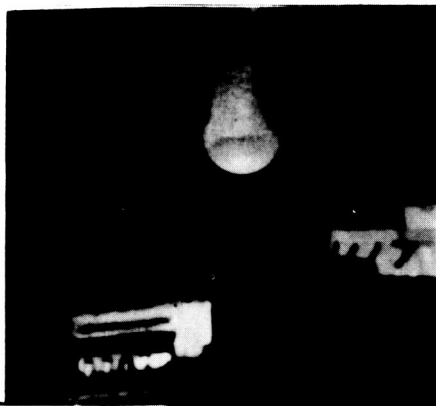


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(b) During the test.

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Figure 6.- Continued.



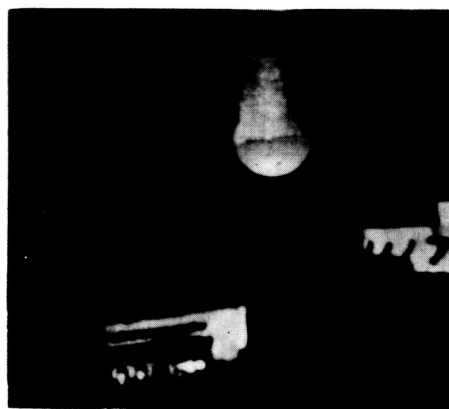
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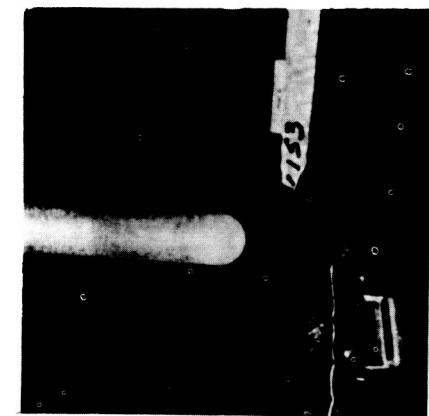
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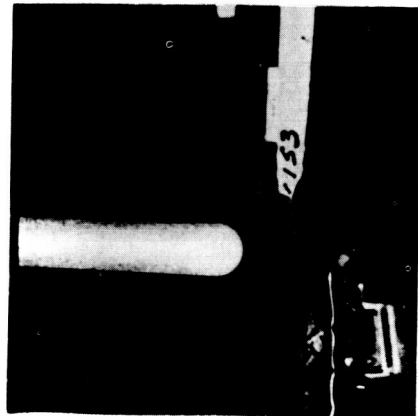
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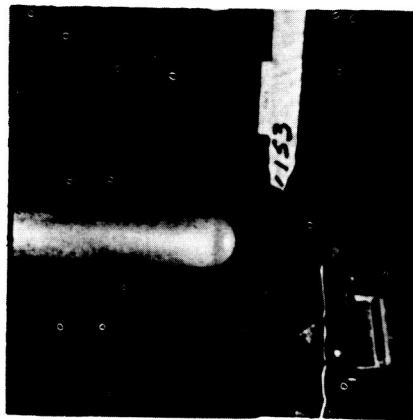
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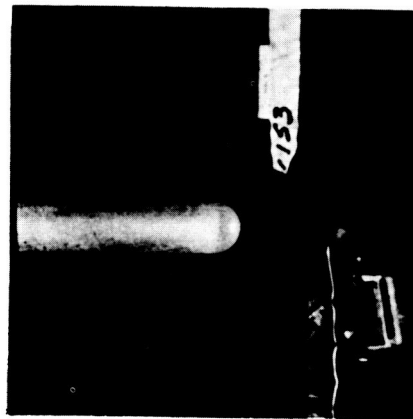
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10 seconds



20 seconds



50 seconds

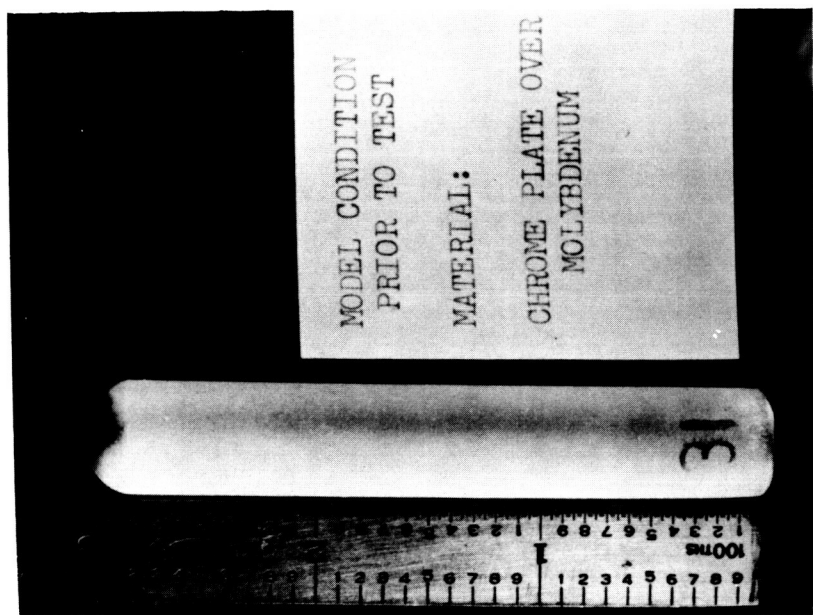
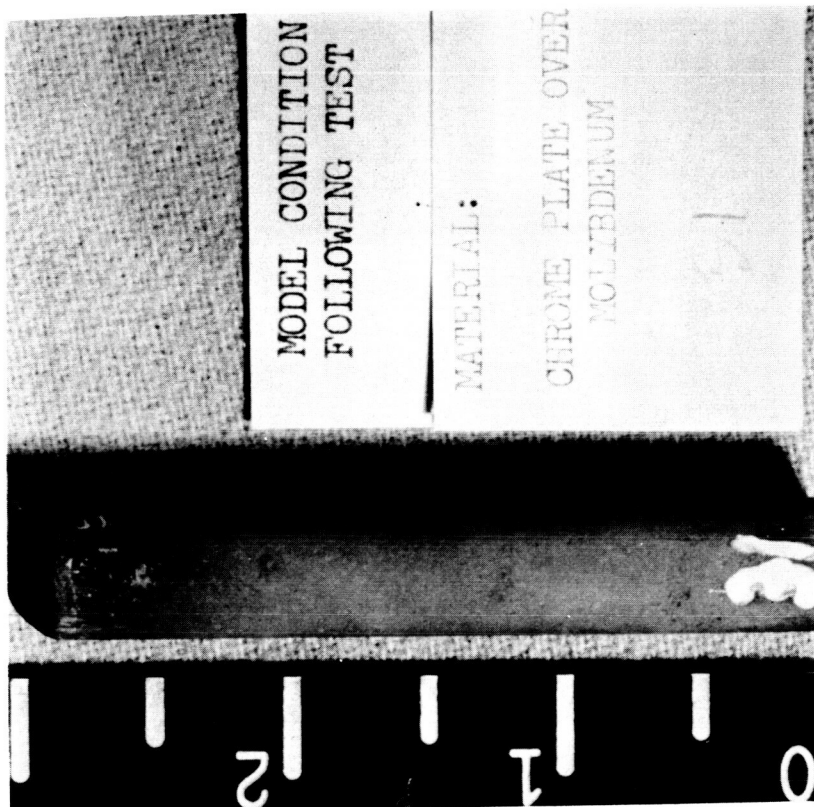


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60 seconds

(c) Model with 1/32 hole in face during the test. L-59-6408

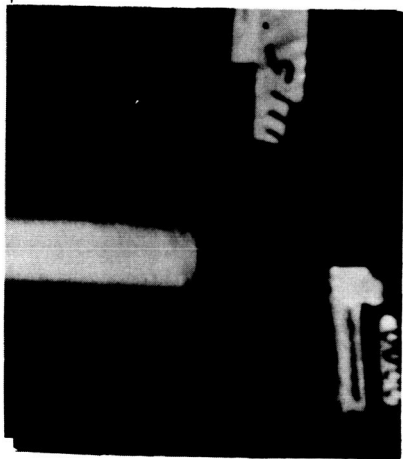
Figure 6.- Concluded.



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(a) Before and after the test.

Figure 7.- Electrodeposited chromium-plated molybdenum model.



0 seconds



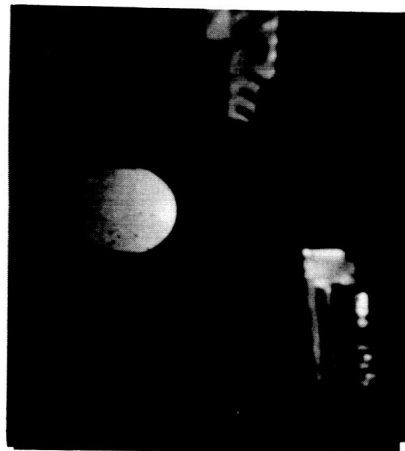
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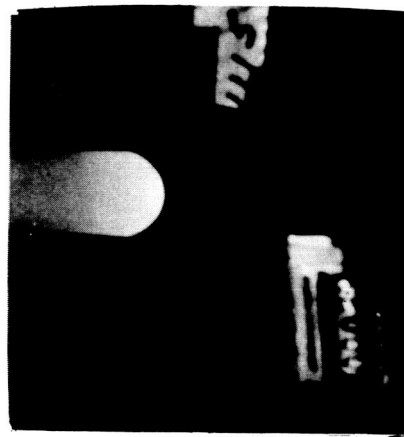
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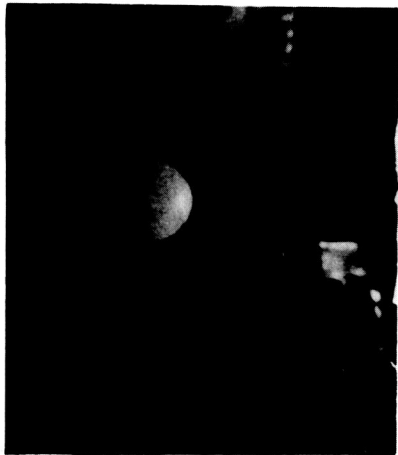


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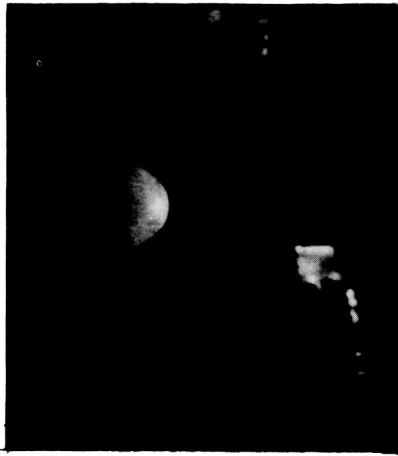
(b) During the test.

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Figure 7.- Continued.



24 seconds



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32 seconds



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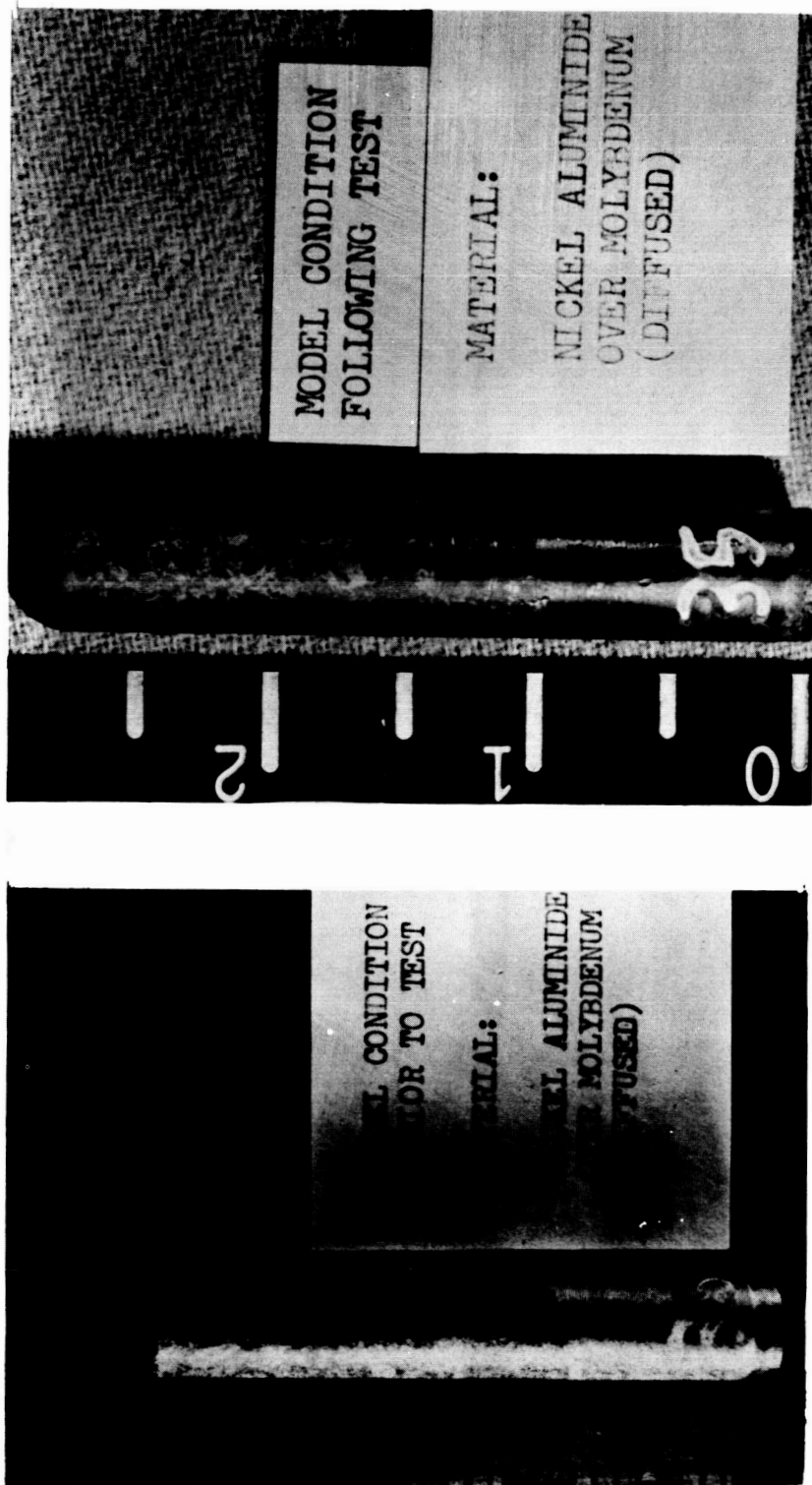


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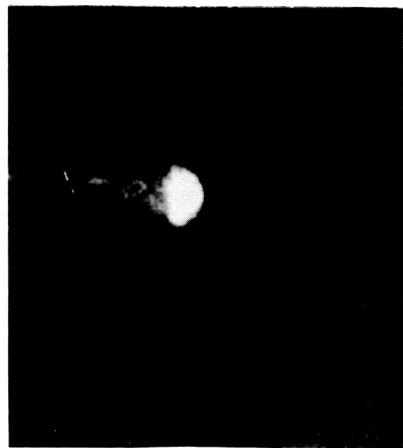
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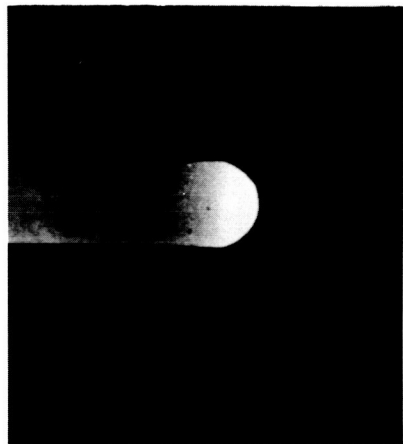


(a) Before and after the test. L-59-6412

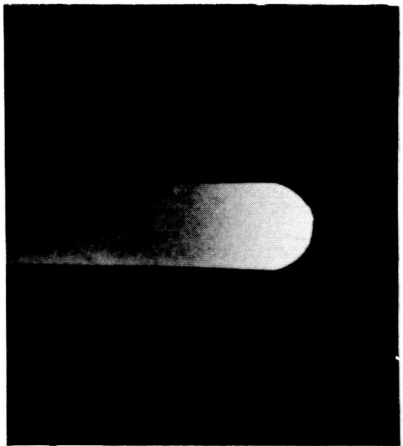
Figure 8.- Nickel aluminide coated molybdenum model.



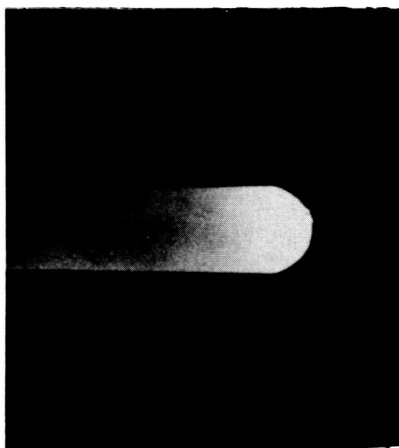
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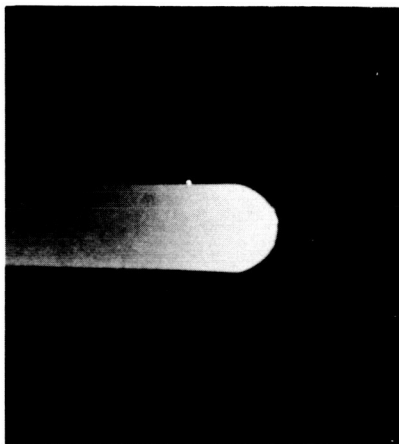
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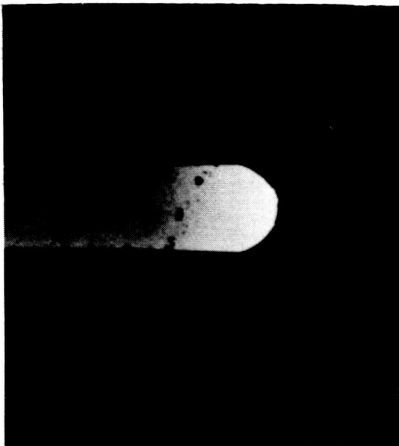
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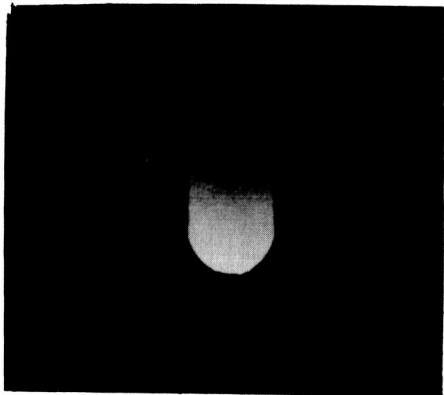
35 seconds

L-59-6413

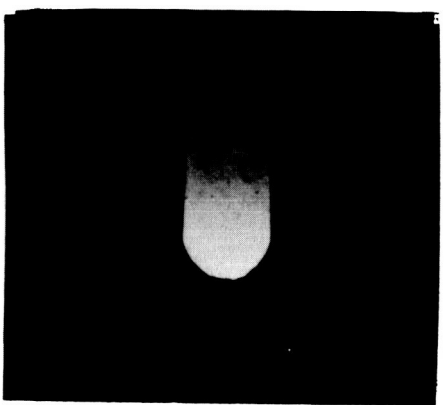
(b) During the test.

Figure 8.- Continued.

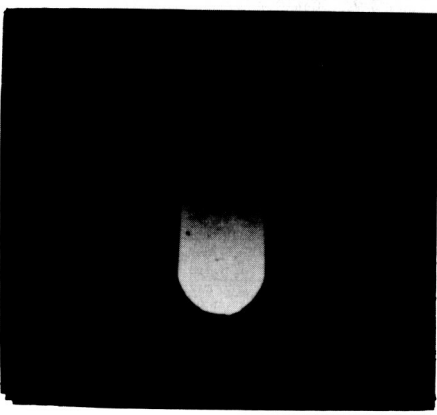
L-725



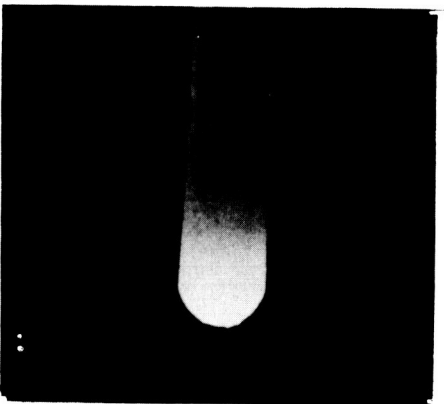
41 seconds



48 seconds



55 seconds

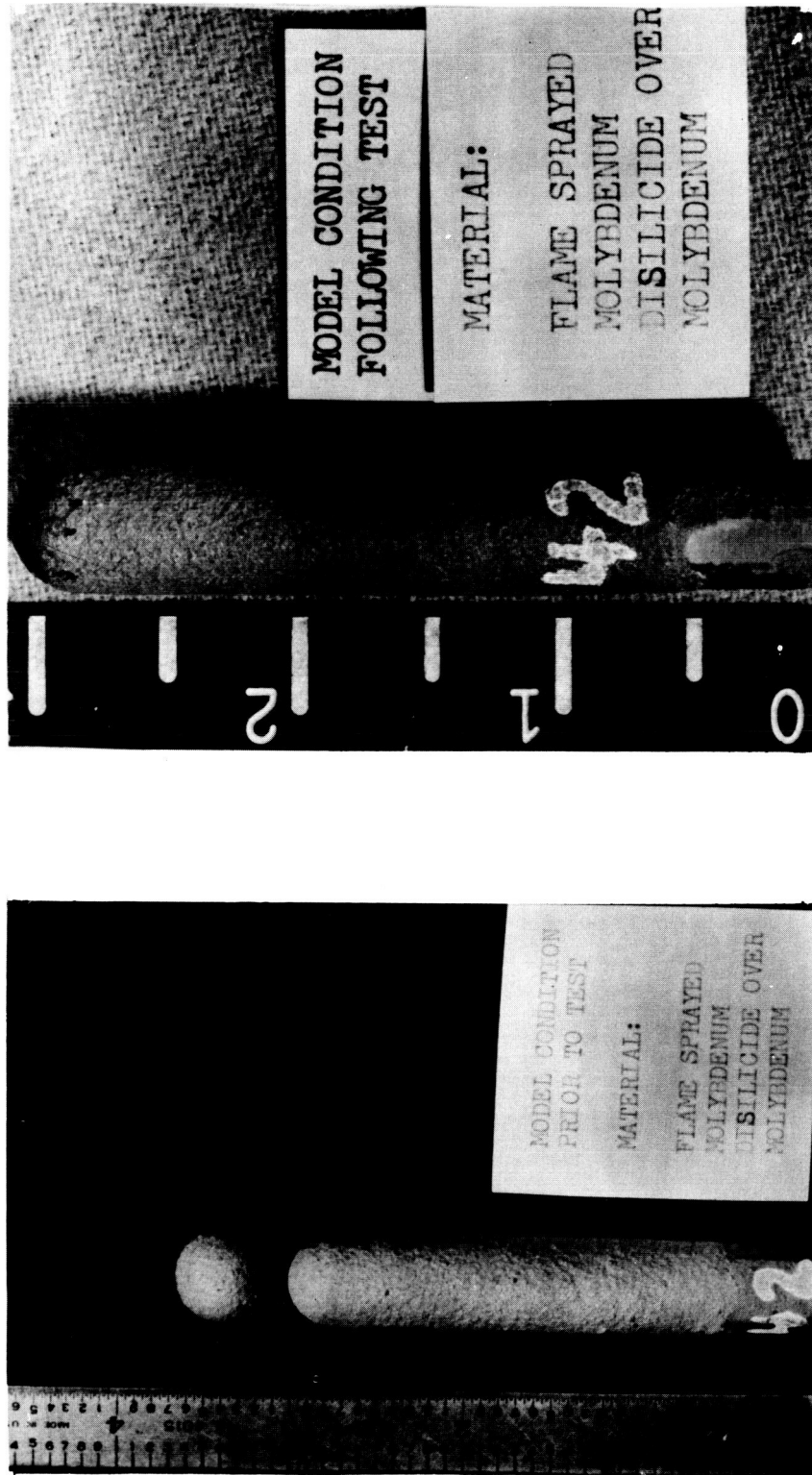


58 seconds

(b) Concluded.

L-59-6414

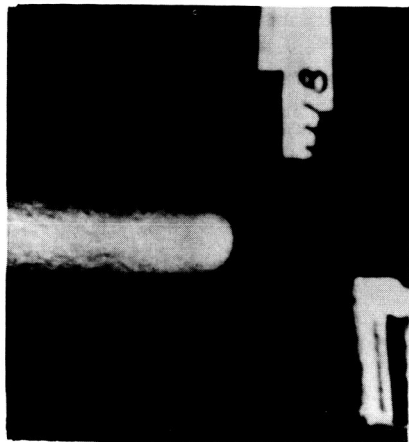
Figure 8.- Concluded.



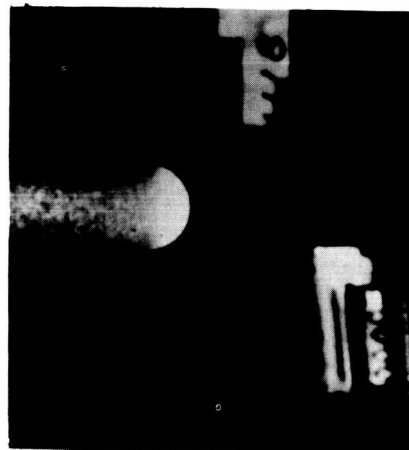
(a) Before and after the test.

I-59-6415

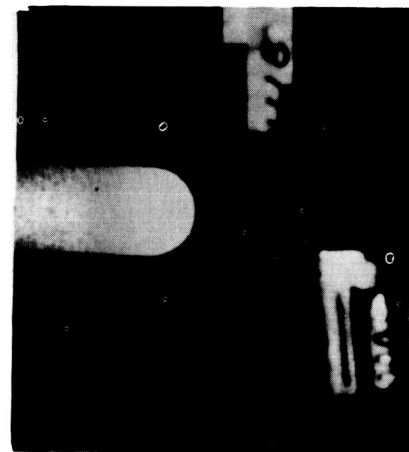
Figure 9.- Flame-sprayed molybdenum disilicide coated molybdenum model.



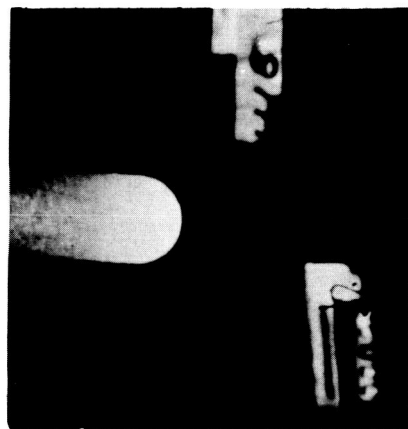
0 seconds



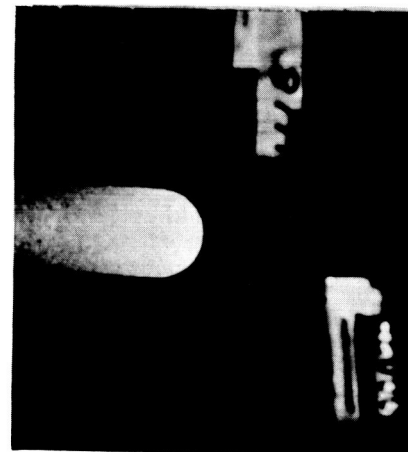
7 seconds



14 seconds



20 seconds



27 seconds

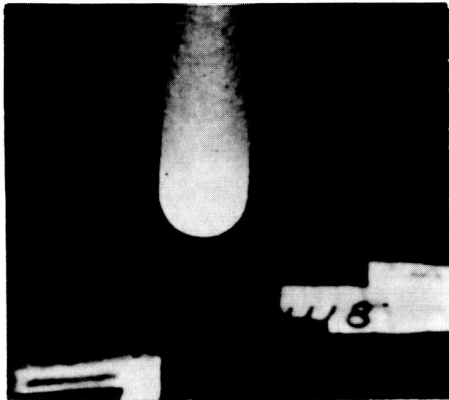


33 seconds

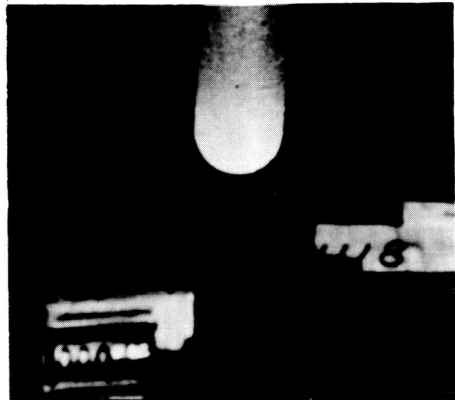
(b) During the test.

L-59-6416

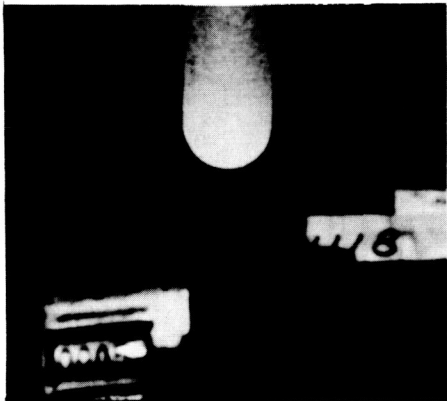
Figure 9.- Continued.



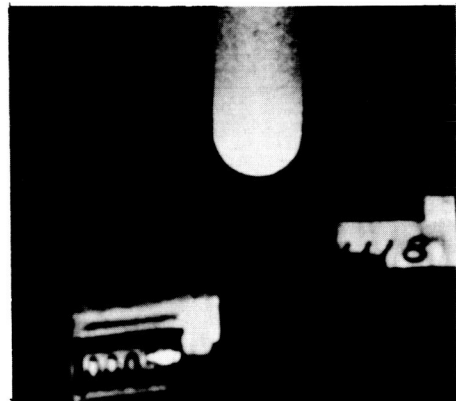
39 seconds



46 seconds



52 seconds

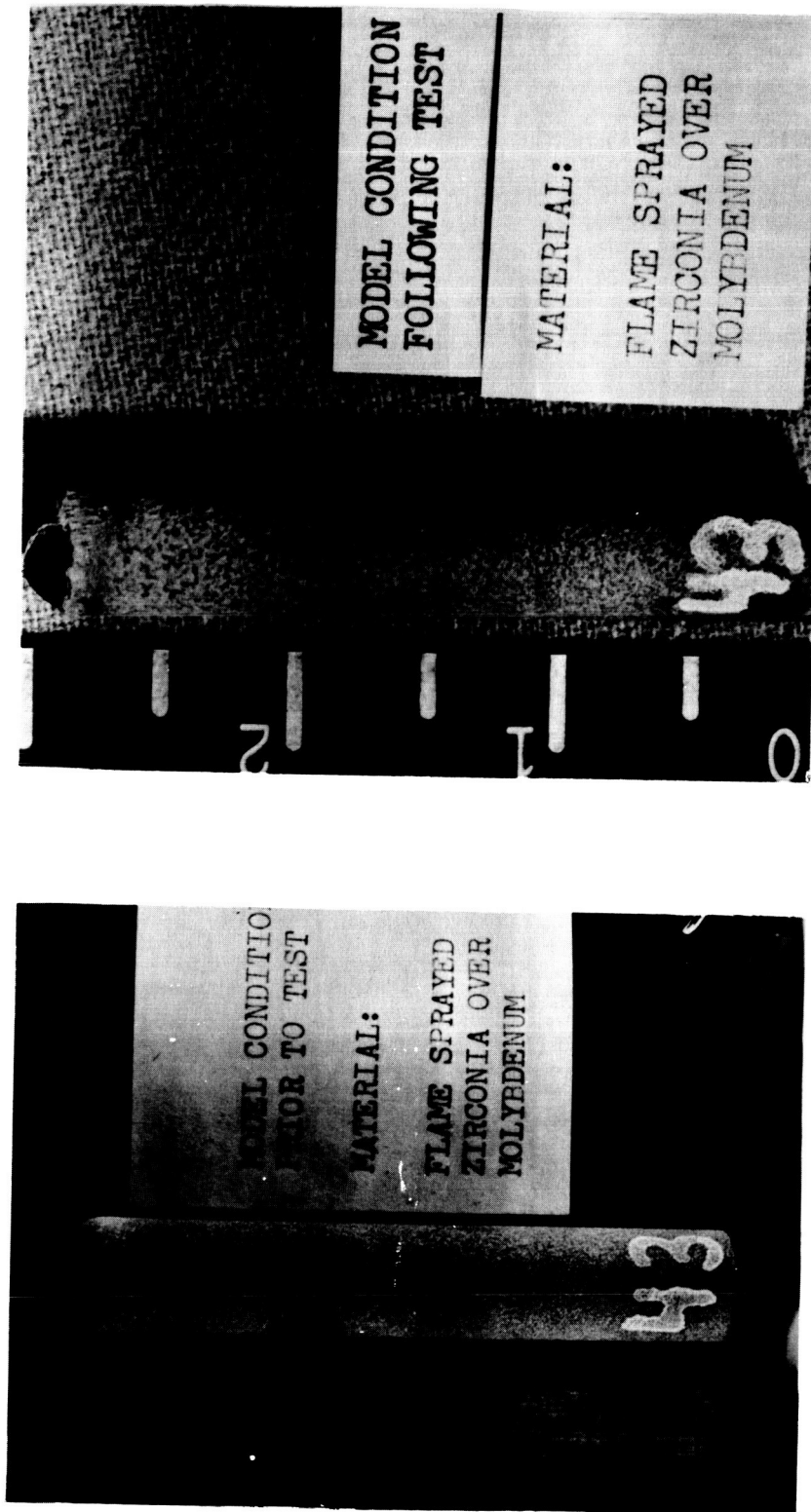


57 seconds

(b) Concluded.

L-59-6417

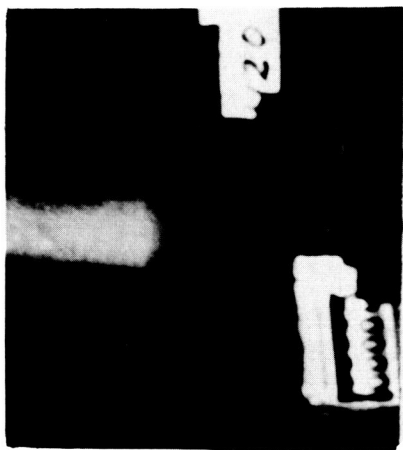
Figure 9.- Concluded.



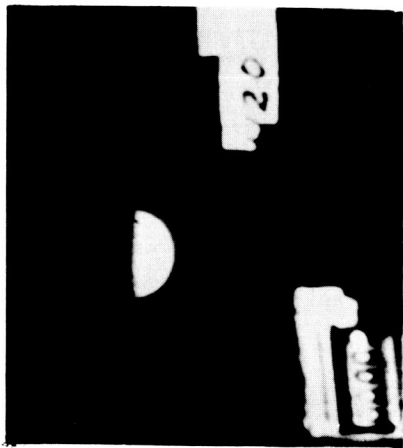
(a) Before and after the test.

L-59-6418

Figure 10.- Flame-sprayed zirconia molybdenum laminate over molybdenum model.



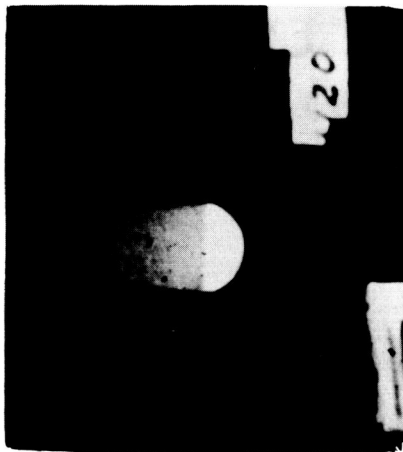
0 seconds



7 seconds



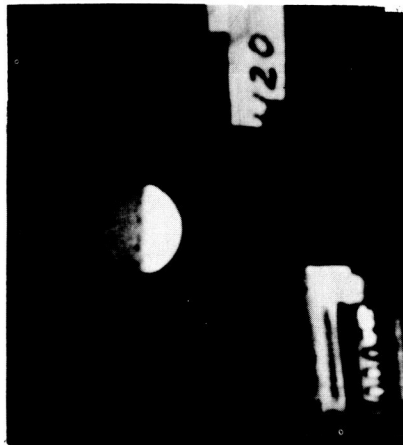
14 seconds



21 seconds



28 seconds

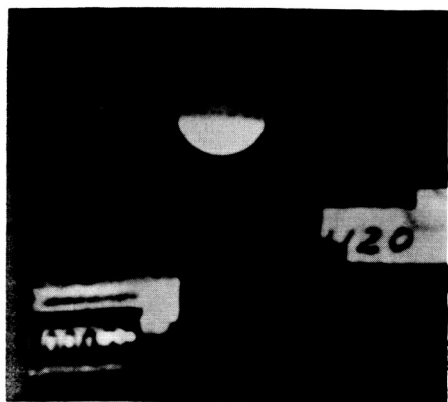


32 seconds

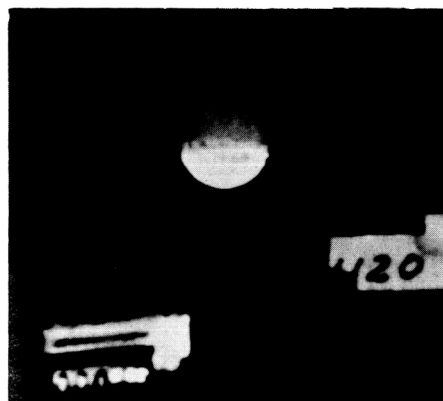
(b) During the test.

L-59-6419

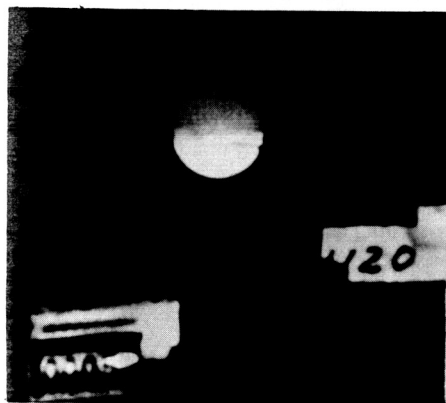
Figure 10.- Continued.



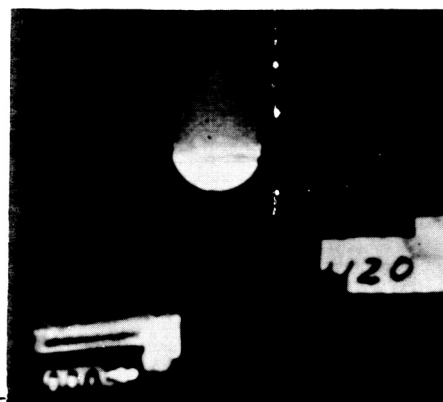
38 seconds



45 seconds



52 seconds

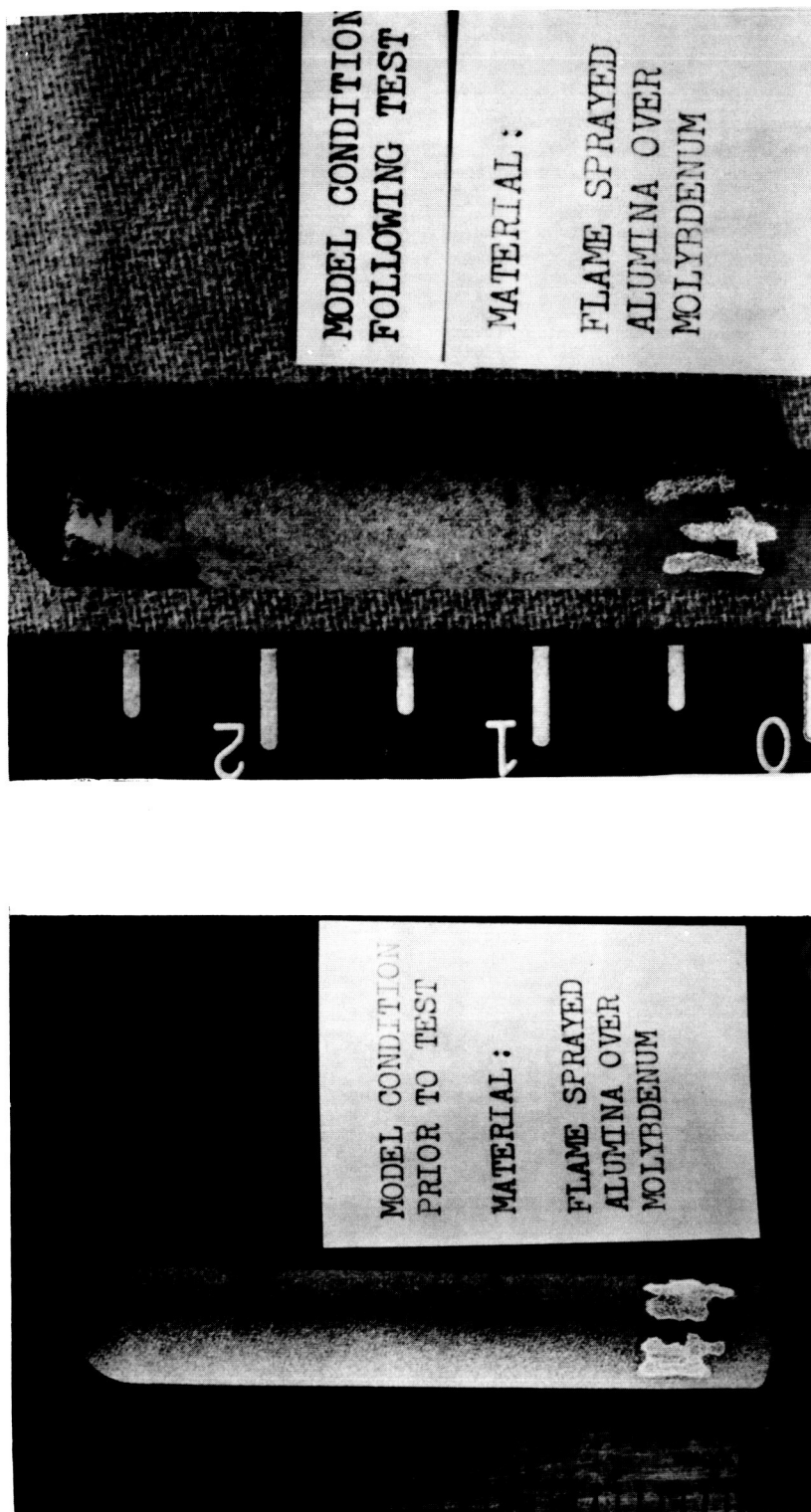


58 seconds

(b) Concluded.

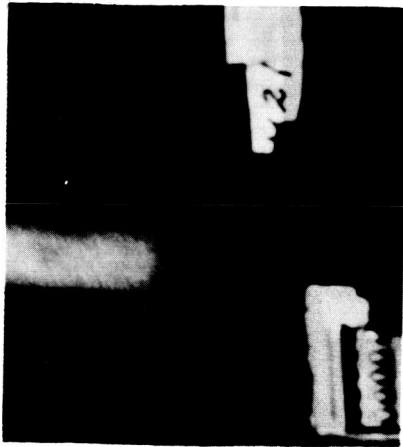
L-59-6420

Figure 10.- Concluded.



(a) Before and after the test. L-59-6421

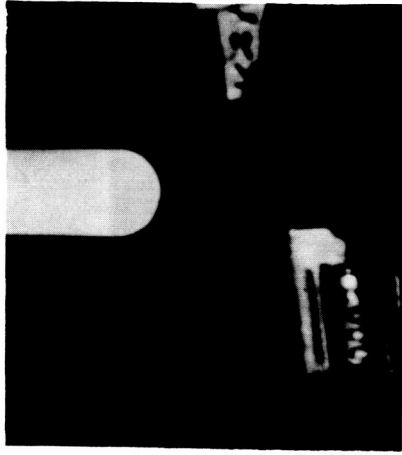
Figure 11.- Flame-sprayed alumina molybdenum laminate coated molybdenum model.



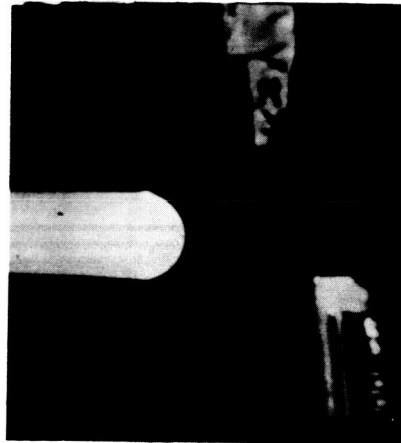
0 seconds



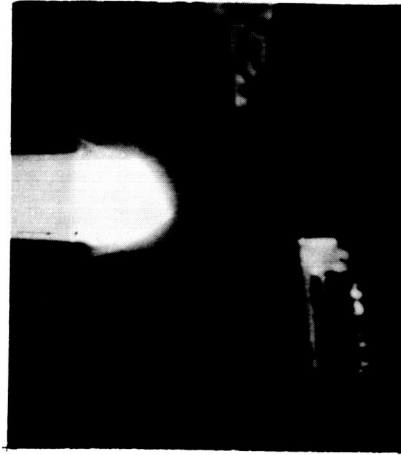
7 seconds



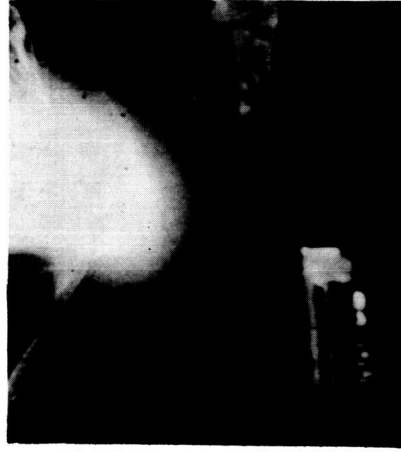
21 seconds



28 seconds



35 seconds

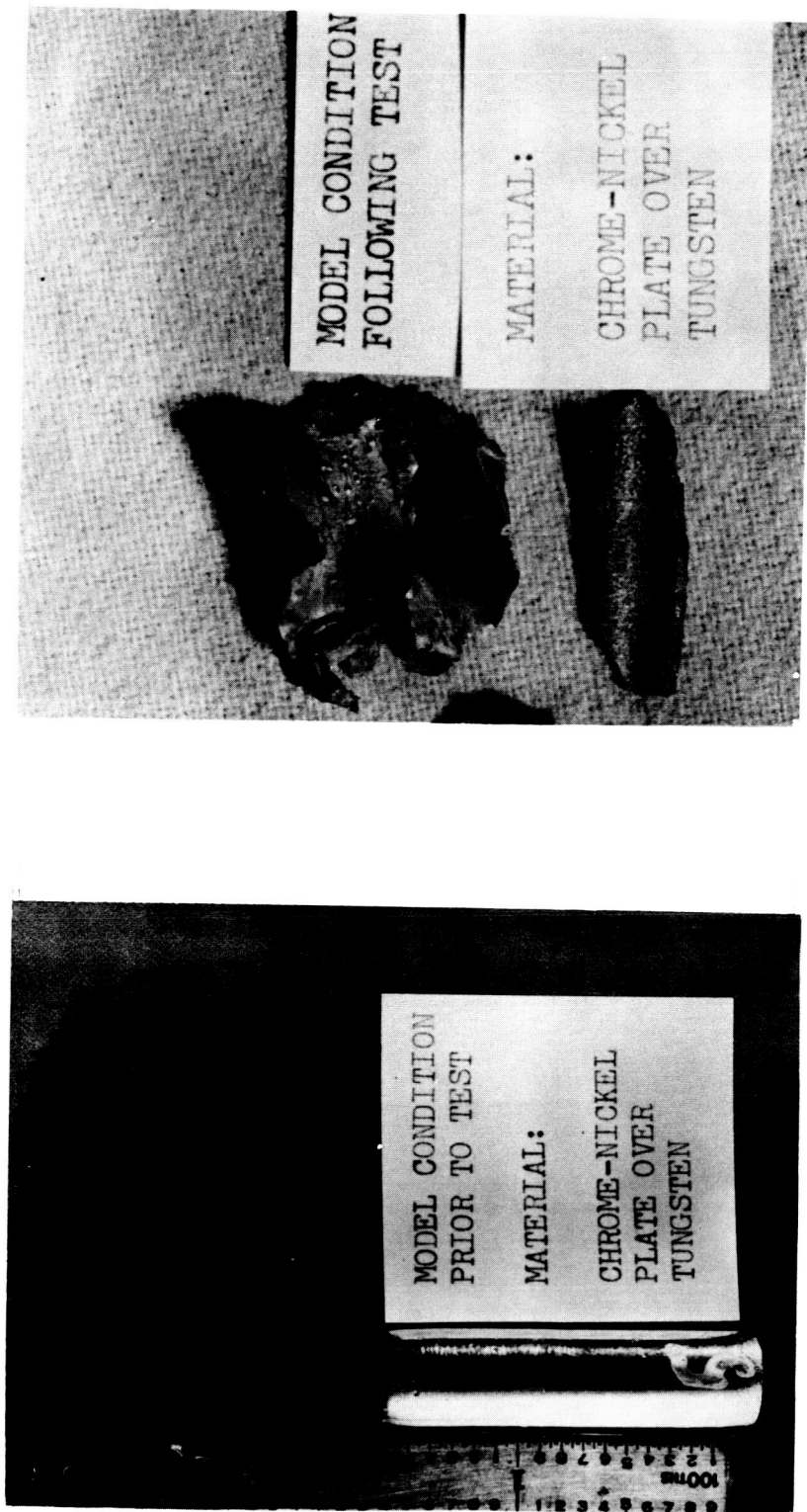


37 seconds

(b) During the test.

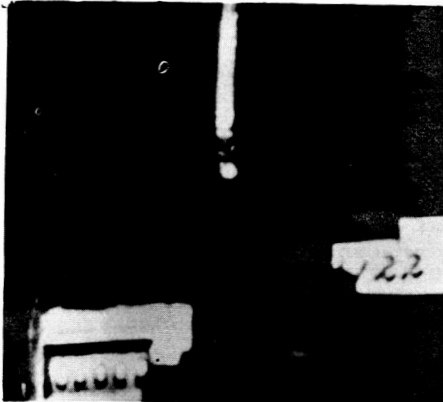
L-59-6422

Figure 11.- Concluded.

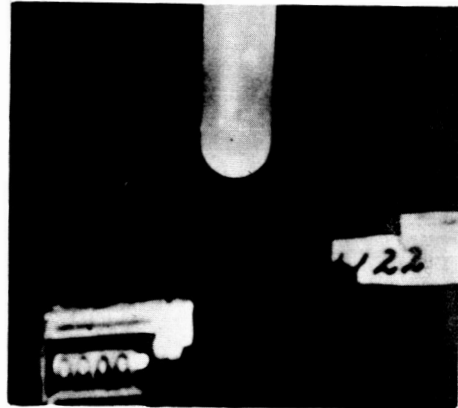


(a) Before and after the test. L-59-6423

Figure 12.- Chrome nickel plate on tungsten model.



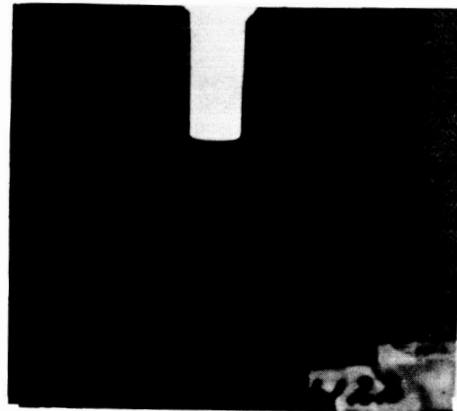
0 seconds



7 seconds



12 seconds

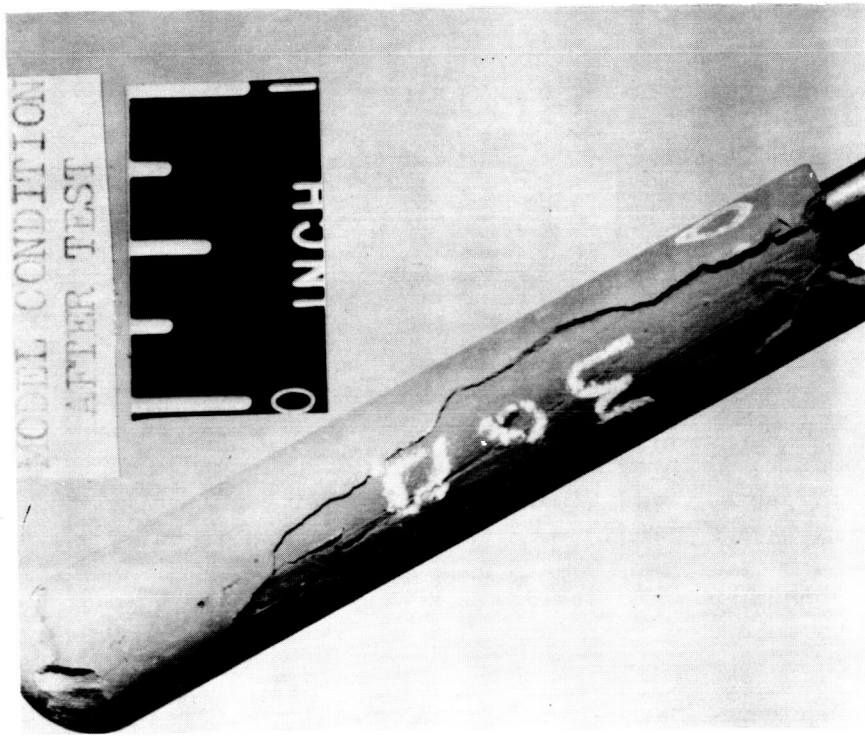


13 seconds

(b) During the test.

L-59-6424

Figure 12.- Concluded.



L-59-6425

(a) Before and after the test.

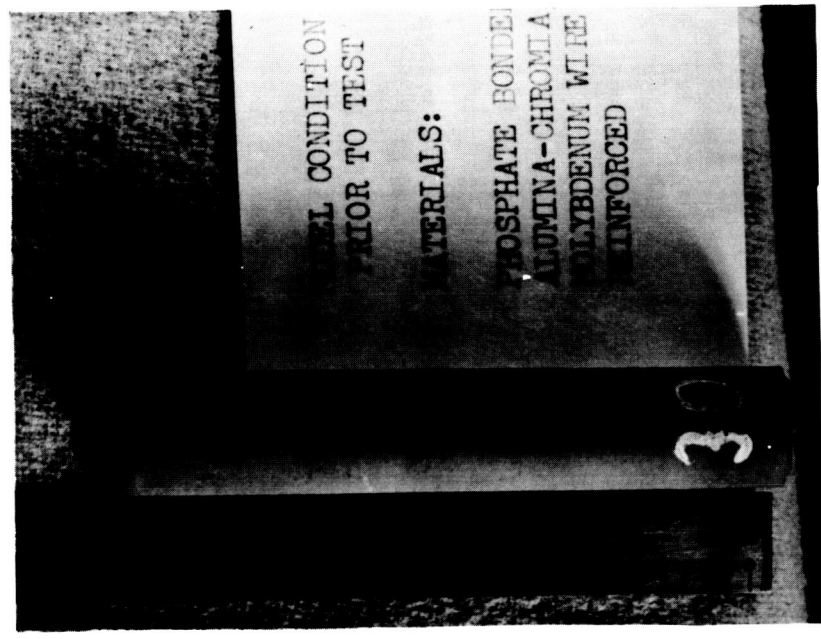
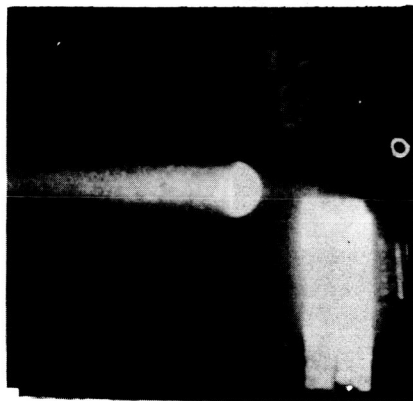
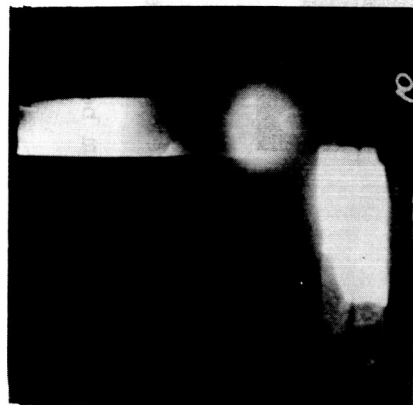


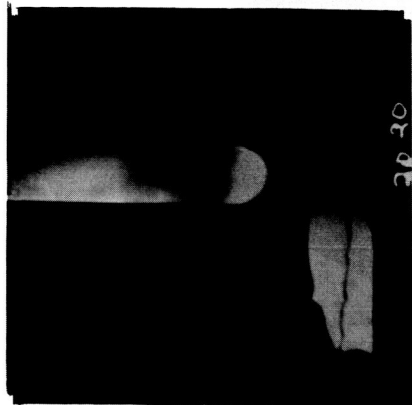
Figure 13.- Phosphate-bonded alumina chromia ceramic model reinforced with spirally wrapped molybdenum wire.



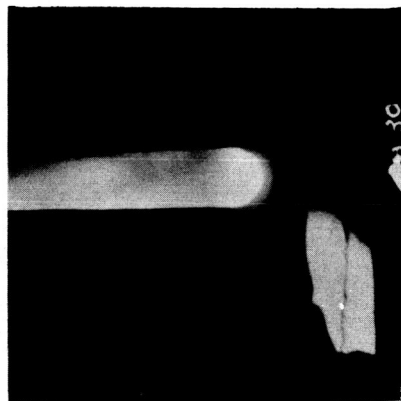
0 seconds



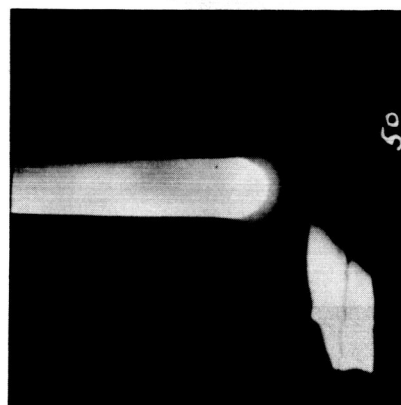
10 seconds



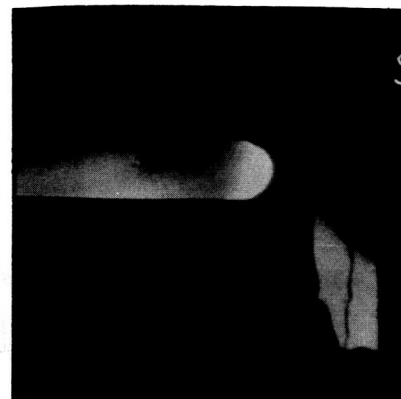
20 seconds



30 seconds



50 seconds

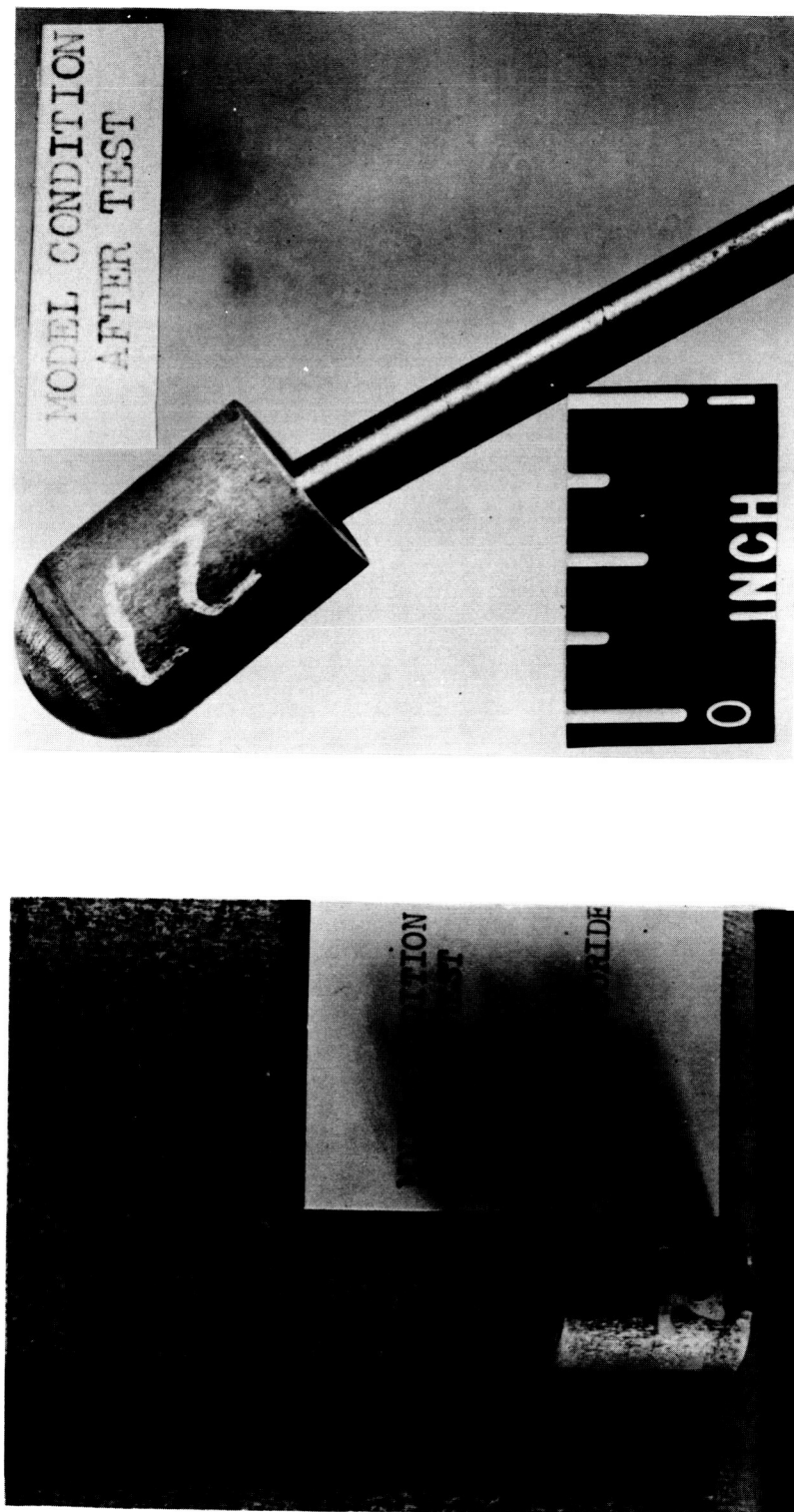


60 seconds

(b) During the test.

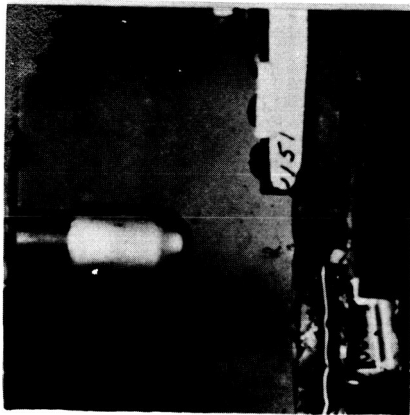
L-59-6426

Figure 13.- Concluded.

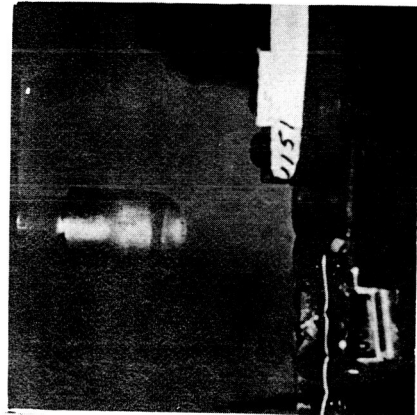


(a) Before and after the test. L-59-6427

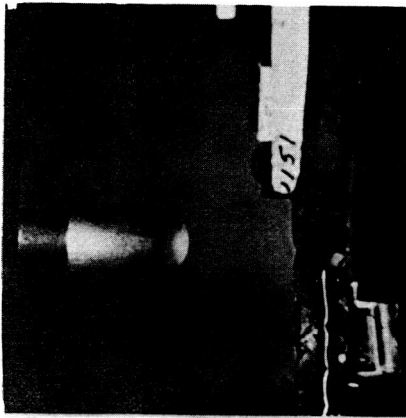
Figure 14.- Zirconium boride model.



0 seconds



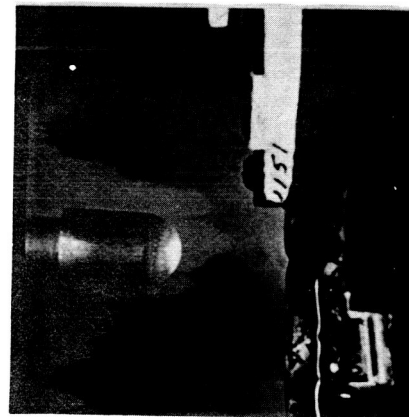
10 seconds



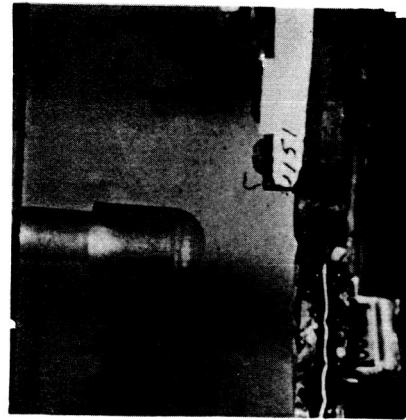
20 seconds



40 seconds



50 seconds

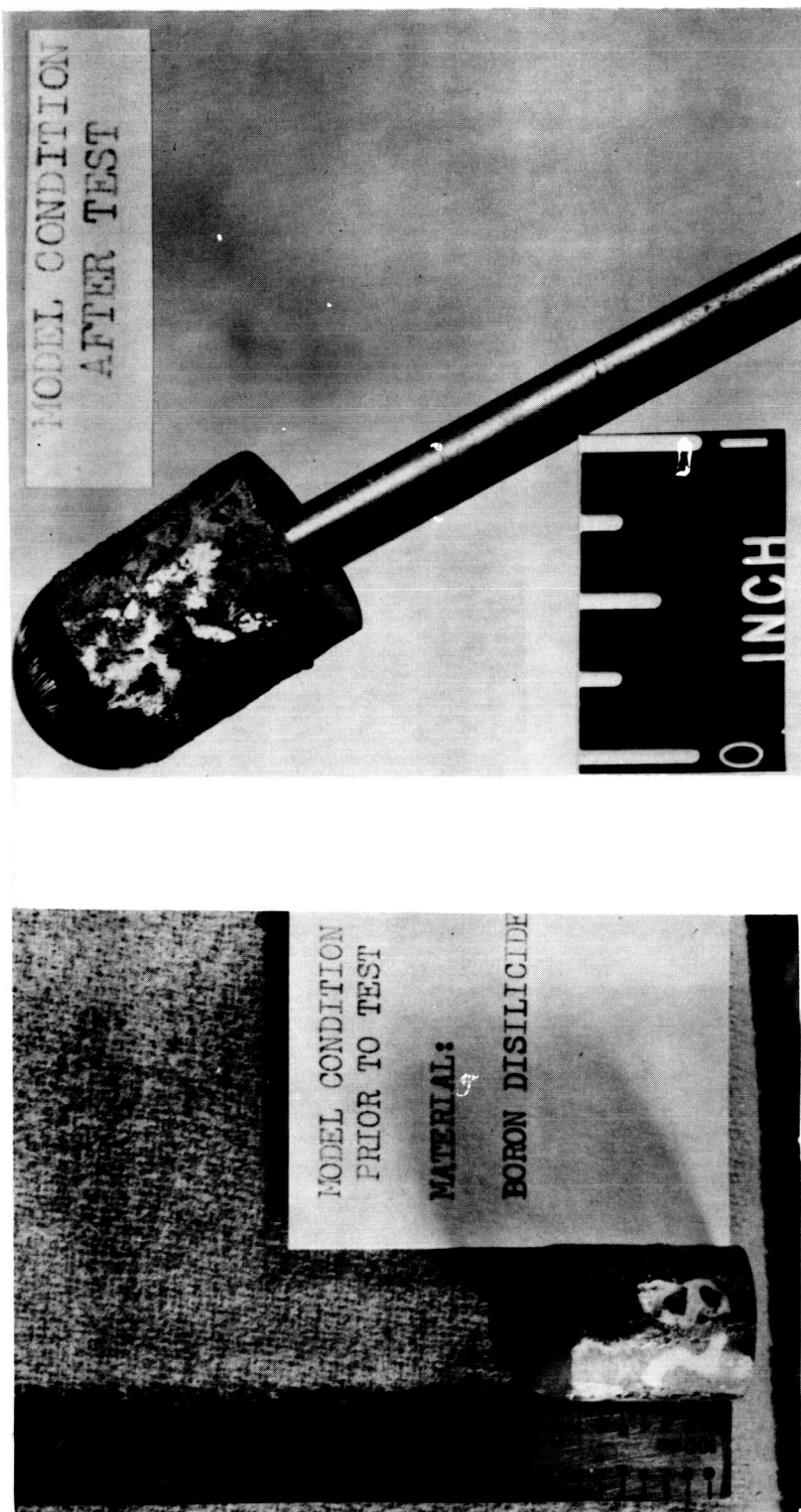


60 seconds

(b) During the test.

I-59-6428

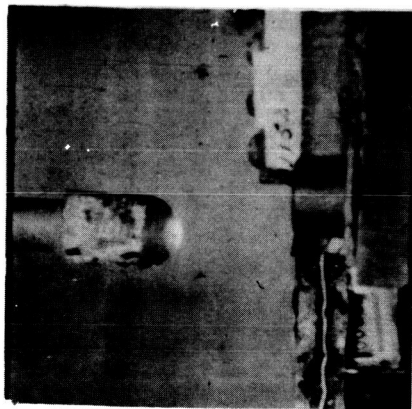
Figure 14.- Concluded.



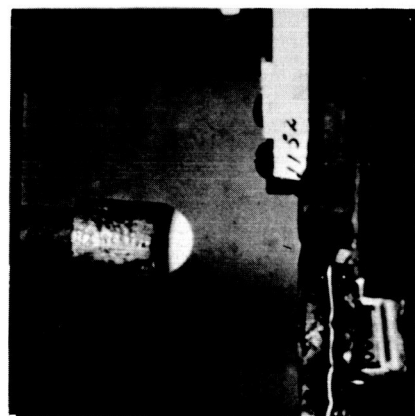
I-59-6429

(a) Before and after the test.

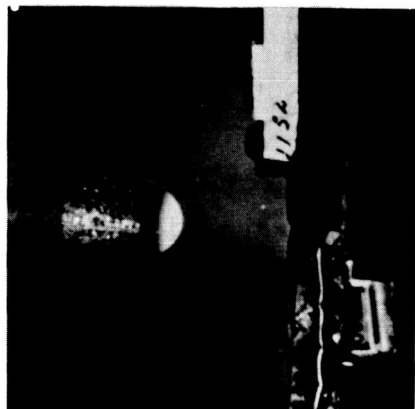
Figure 15.- Siliconized boron model.



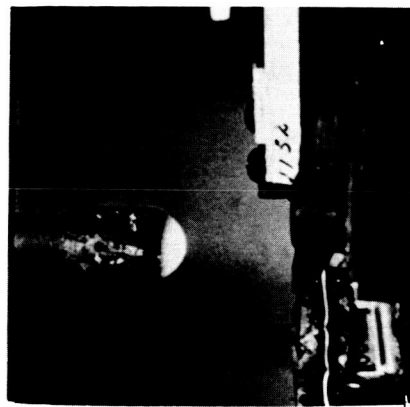
0 seconds



10 seconds



20 seconds



40 seconds



50 seconds

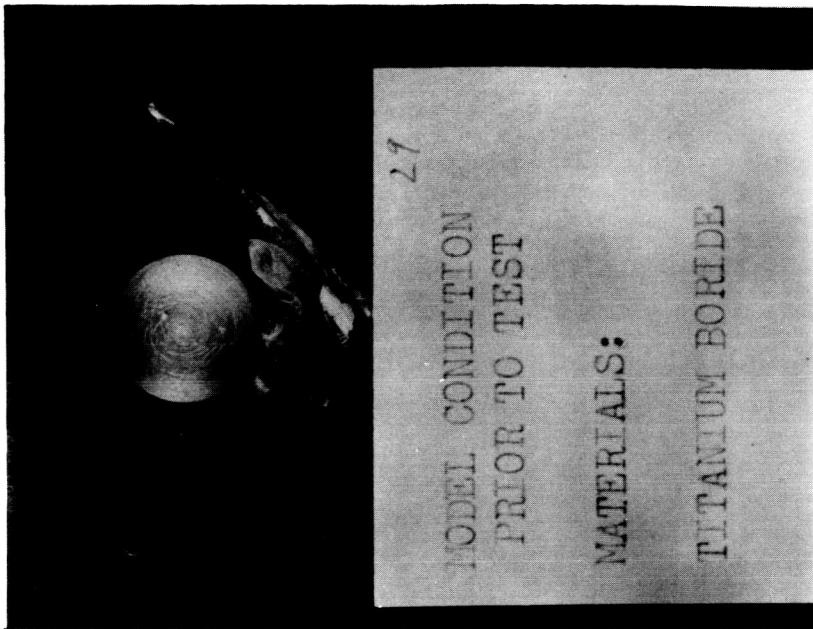
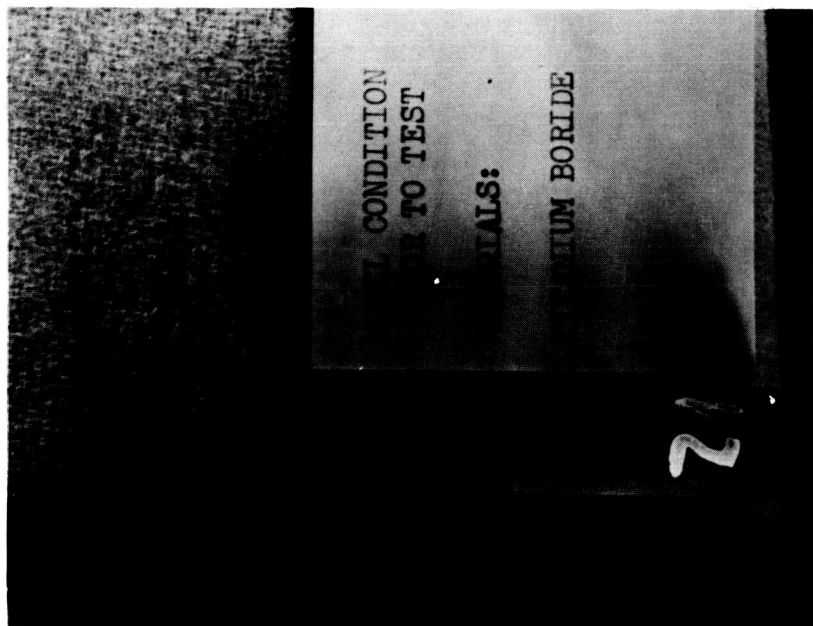


60 seconds

(b) During the test.

L-59-6430

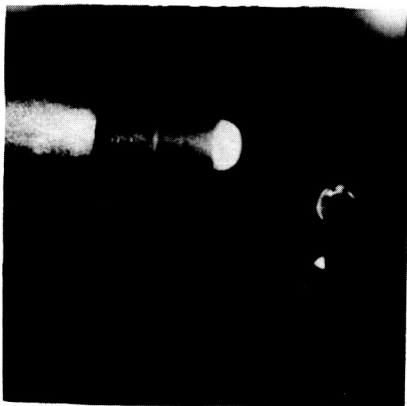
Figure 15.- Concluded.



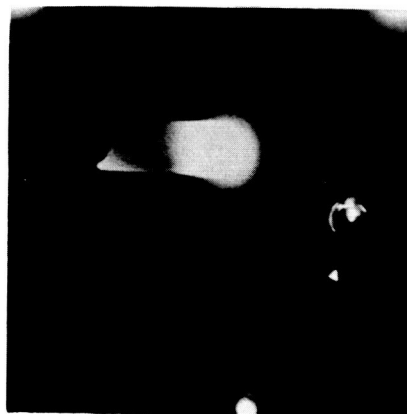
Front view of model

(a) Before the test. L-59-6431

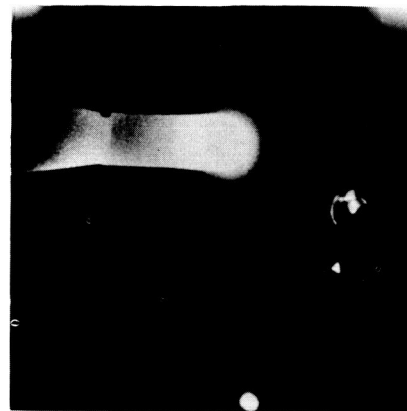
Figure 16.- Titanium boride model.



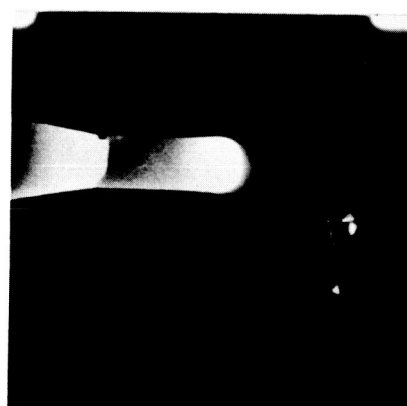
0 seconds



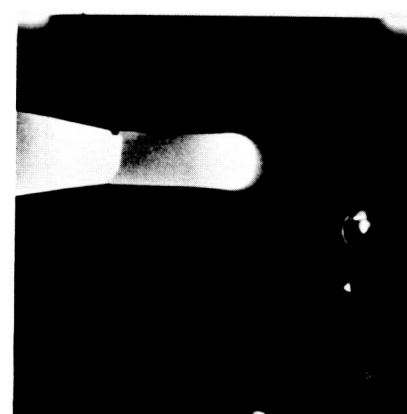
10 seconds



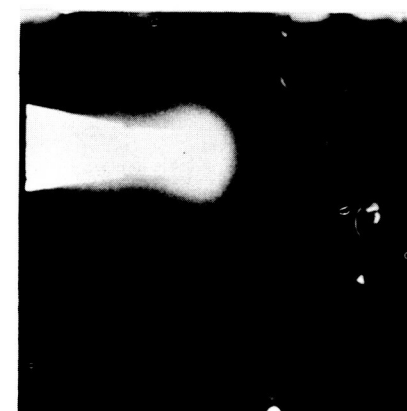
20 seconds



40 seconds



50 seconds

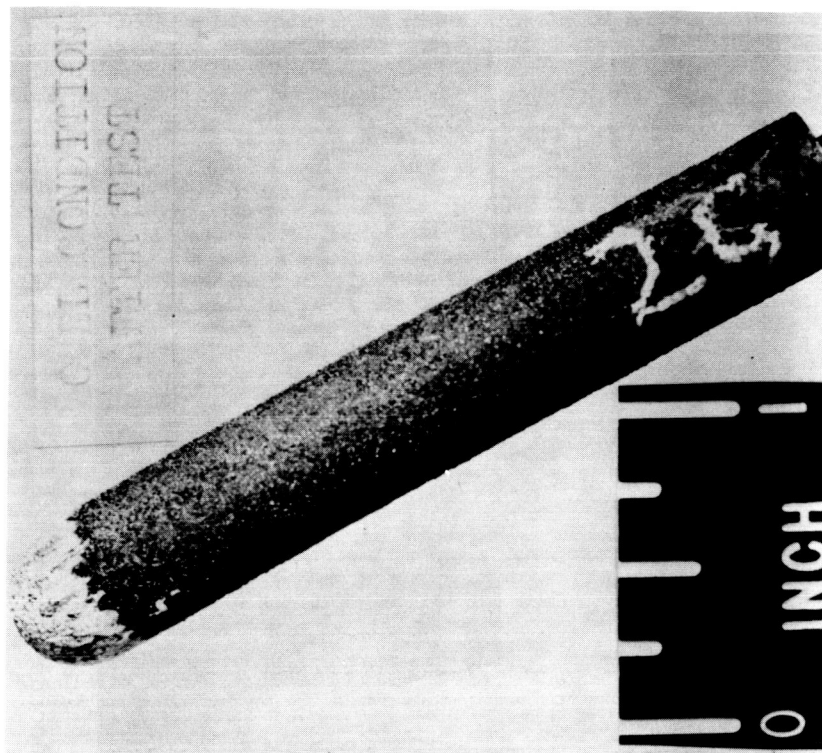


60 seconds

(b) During the test.

L-59-6432

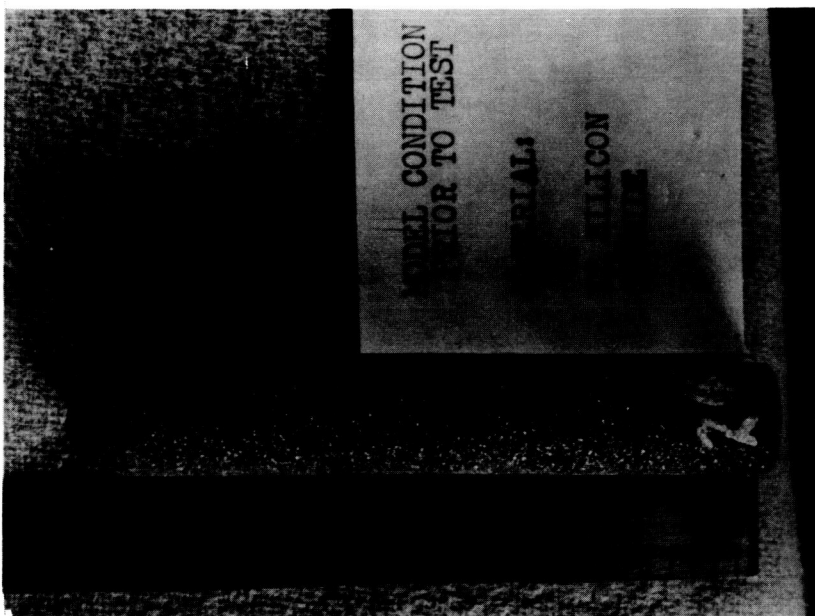
Figure 16.- Concluded.

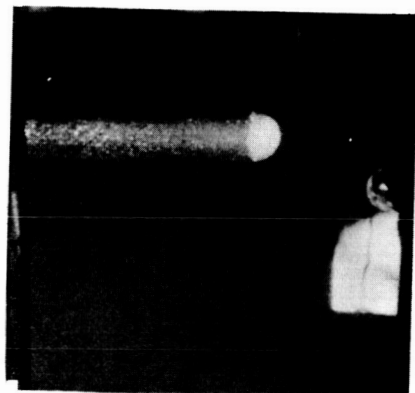


I-59-6433

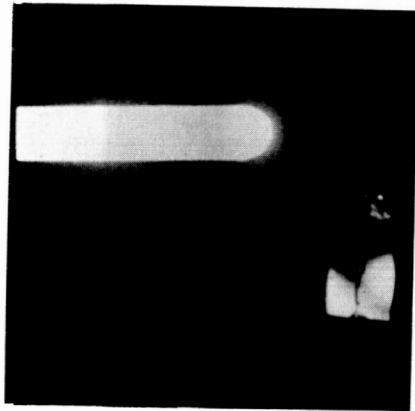
(a) Before and after the test.

Figure 17.- KT silicon carbide model.

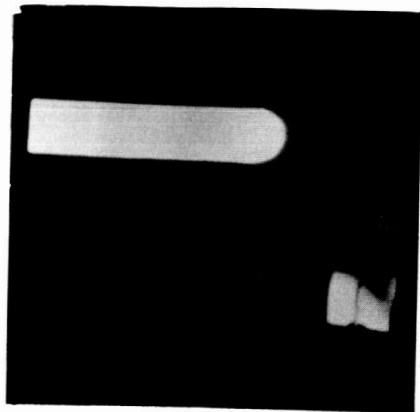




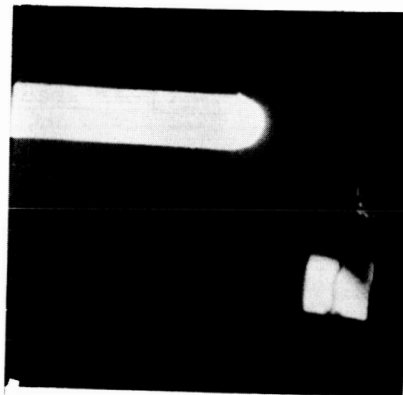
0 seconds



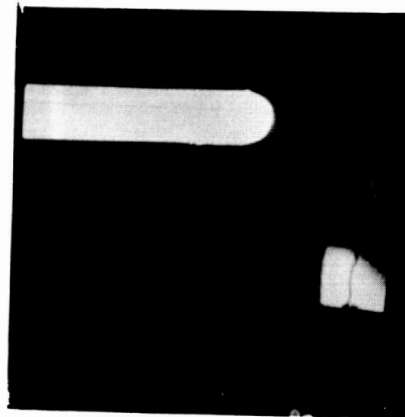
10 seconds



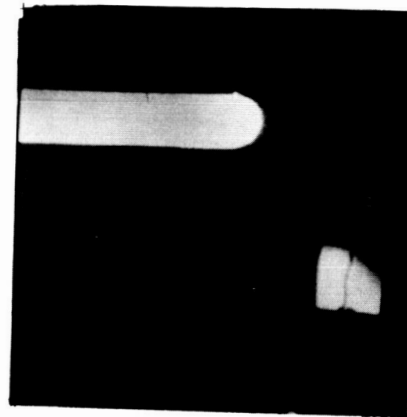
20 seconds



40 seconds



50 seconds

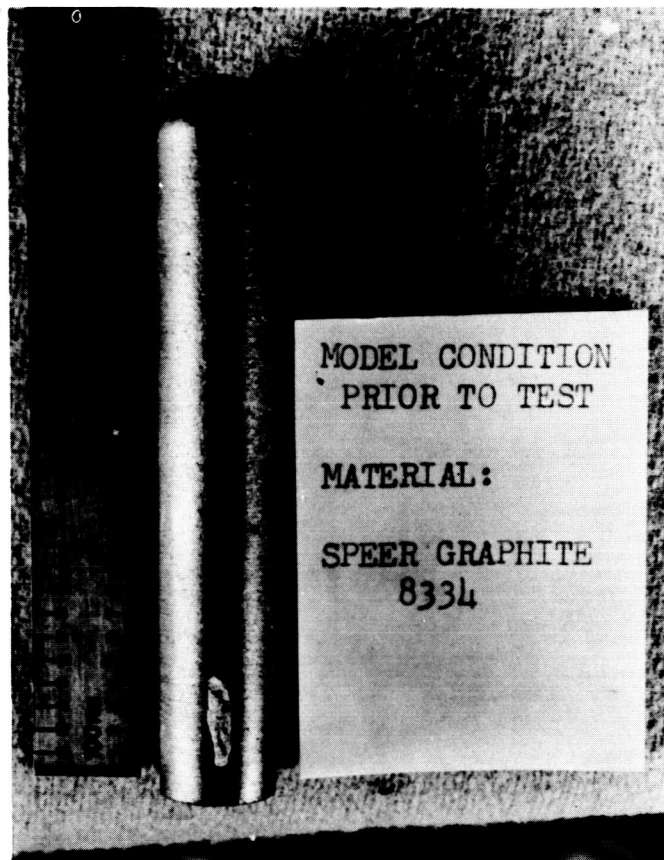


60 seconds

(b) During the test.

Figure 17.- Concluded.

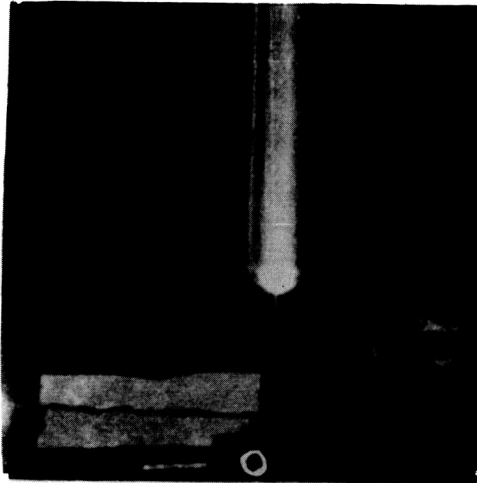
L-59-6434



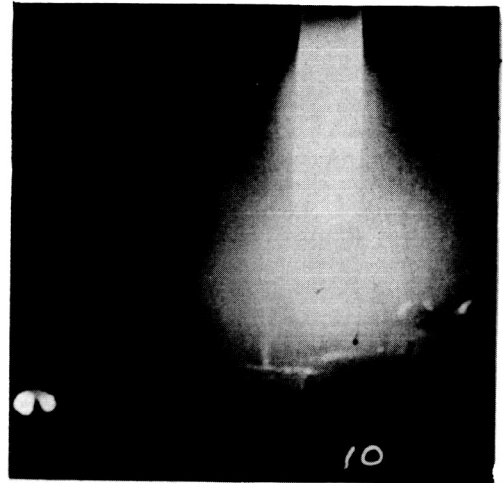
(a) Before the test.

L-59-6435

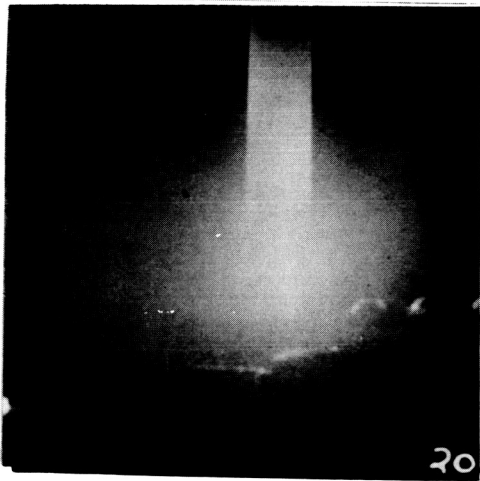
Figure 18.- Speer grade 8334 graphite model.



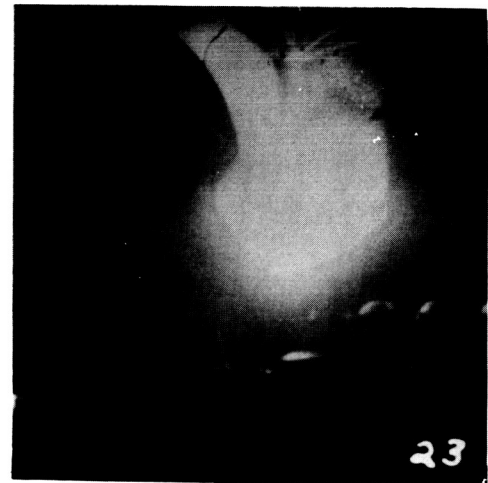
0 seconds



10 seconds



20 seconds

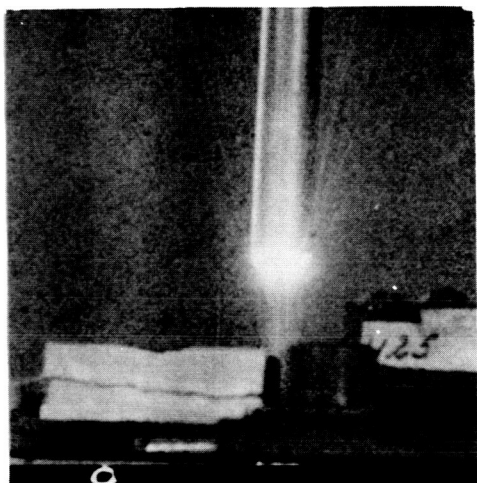


23 seconds

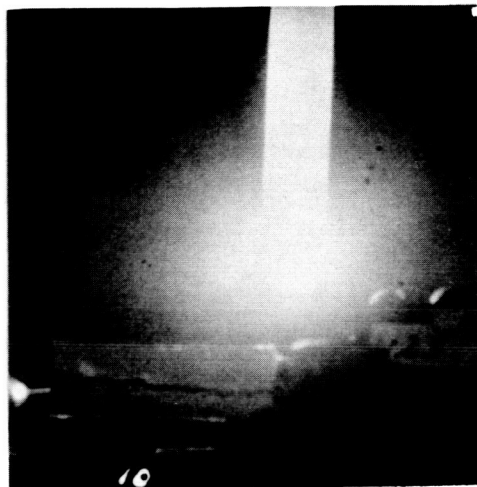
(b) During the test.

L-59-6436

Figure 18.- Continued.



0 seconds



10 seconds



20 seconds



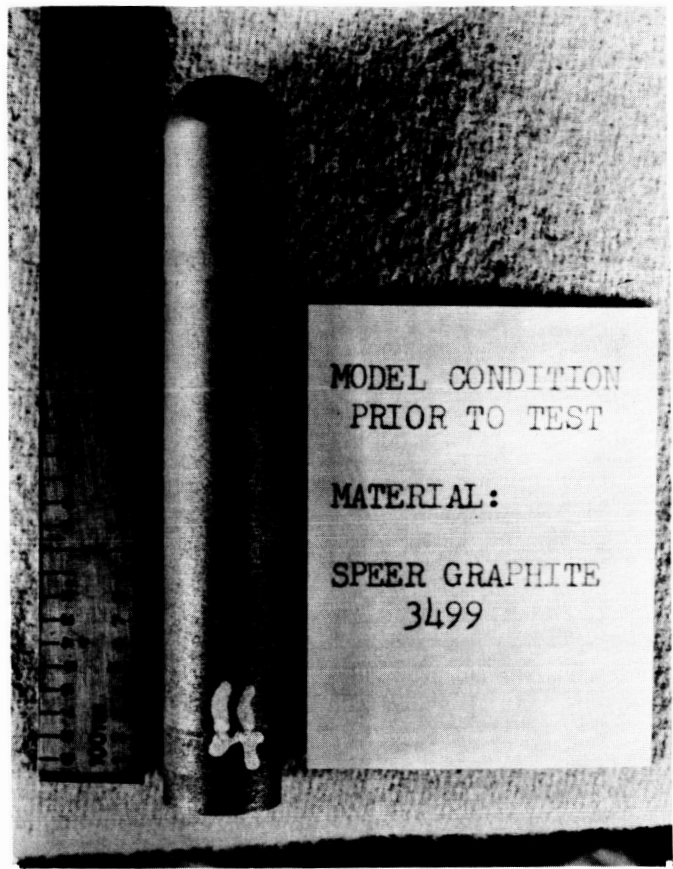
26 seconds

(c) During a duplicate test.

L-59-6437

Figure 18.- Concluded.

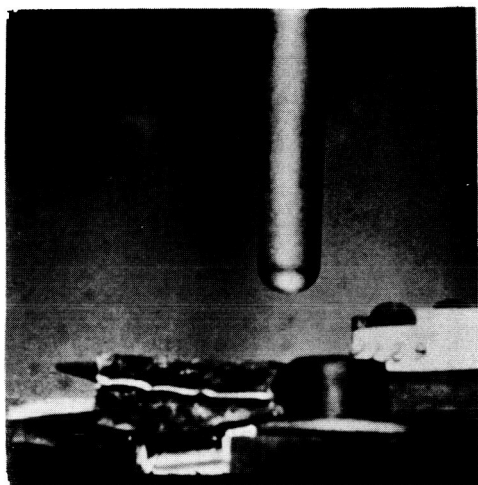
L-725



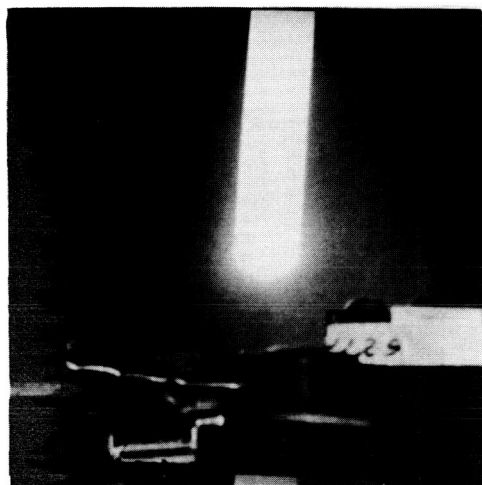
(a) Before the test.

L-59-6438

Figure 19.- Speer grade 3499 graphite model.



0 seconds



10 seconds



20 seconds

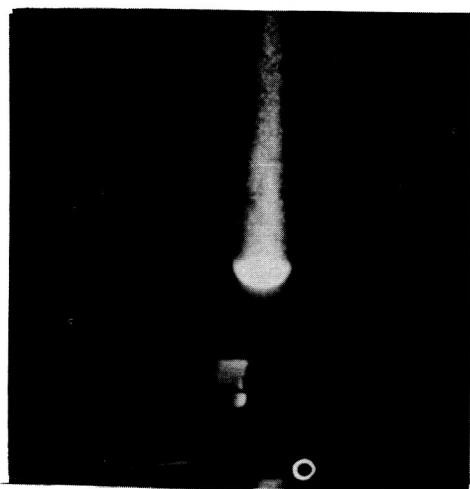


21 seconds

(b) During the test.

L-59-6439

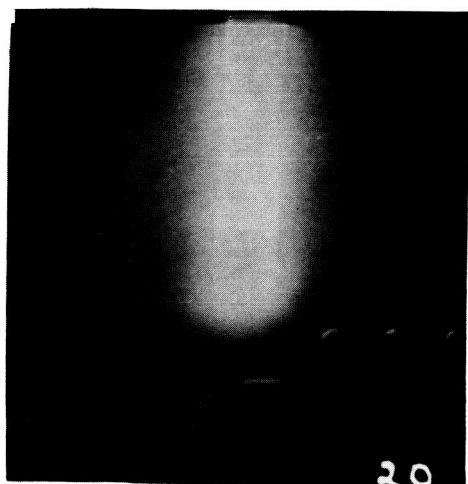
Figure 19.- Continued.



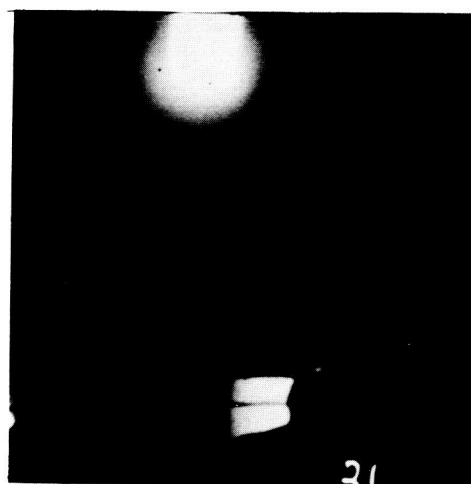
0 seconds



10 seconds



20 seconds

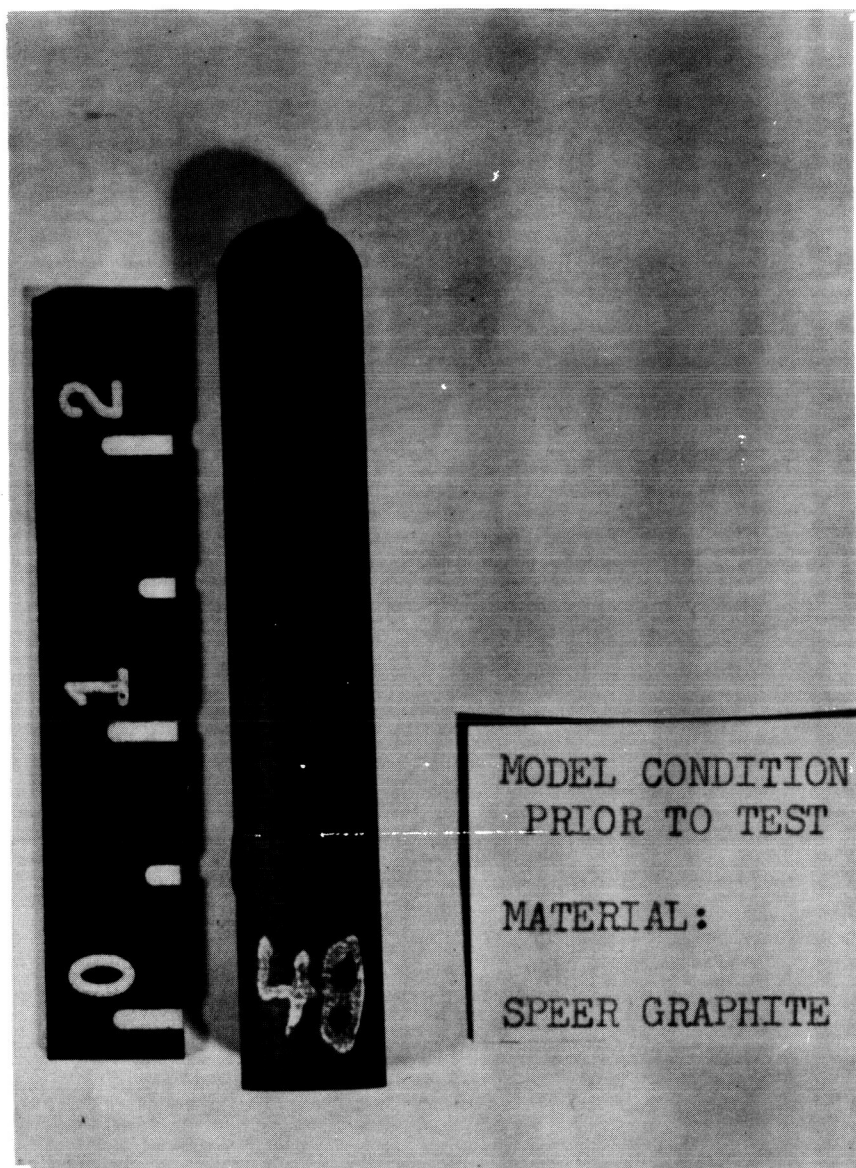


21 seconds

(c) During a duplicate test.

L-59-6440

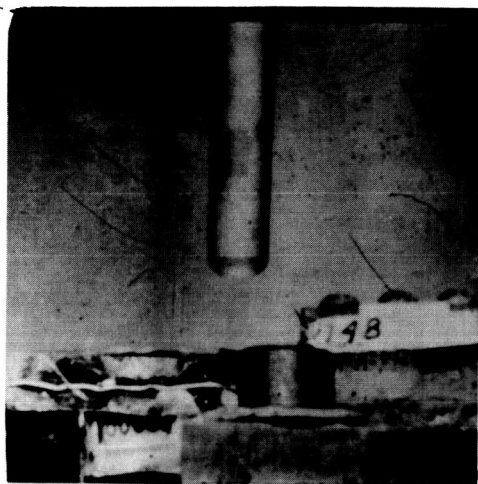
Figure 19.- Concluded.



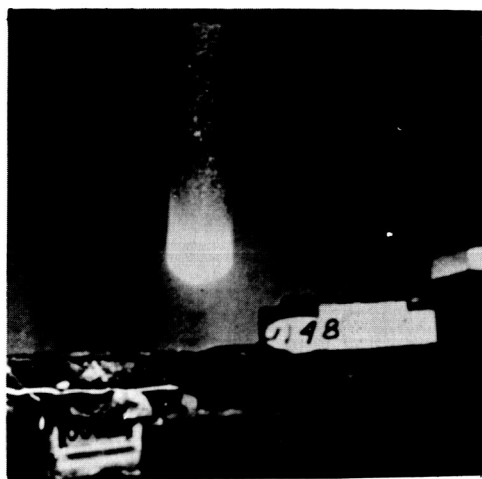
(a) Before the test.

L-59-6441

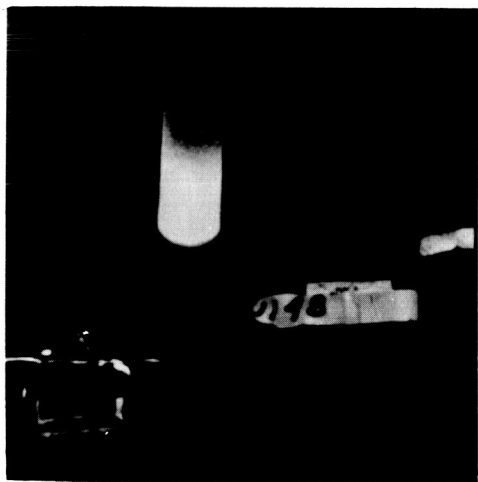
Figure 20.- Speer grade 8204 graphite model.



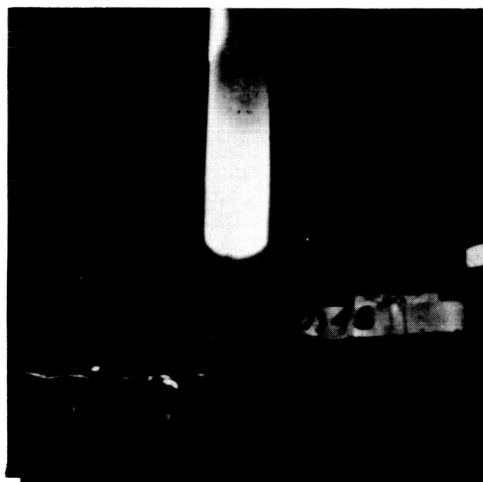
0 seconds



10 seconds



30 seconds

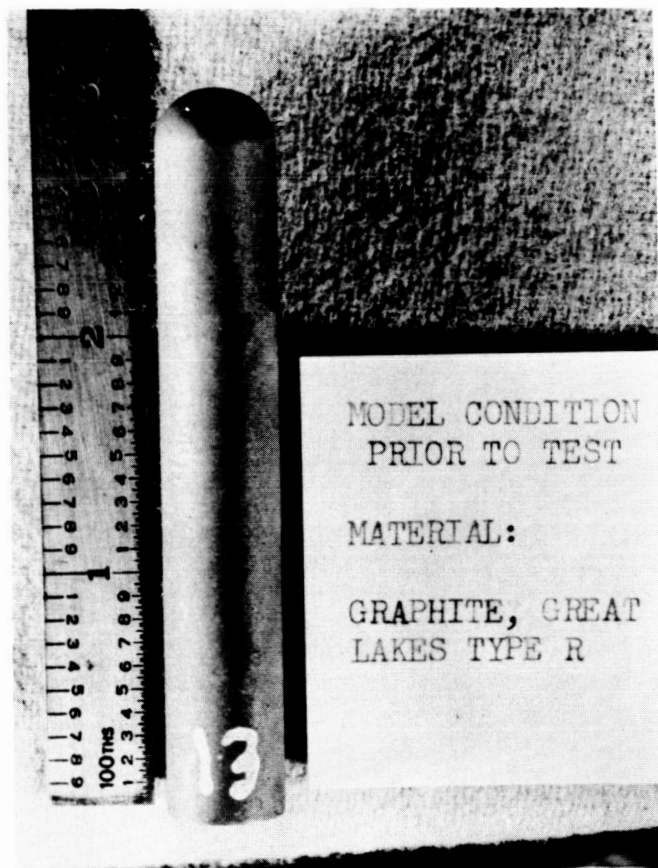


32 seconds

(b) During the test.

L-59-6442

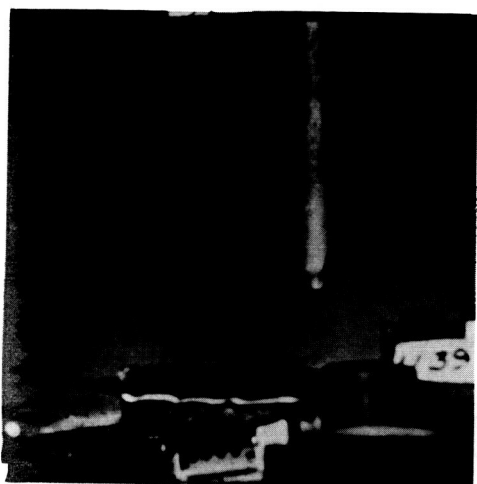
Figure 20.- Concluded.



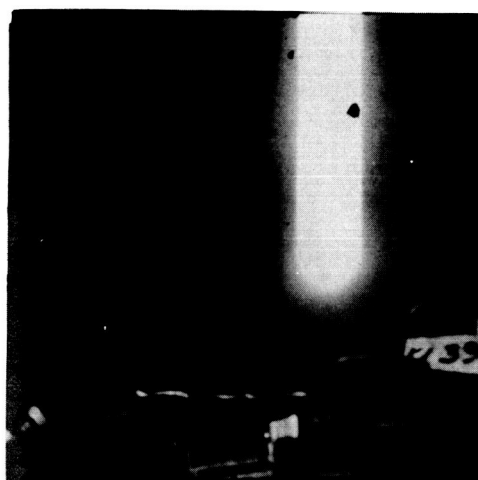
(a) Before the test.

L-59-6443

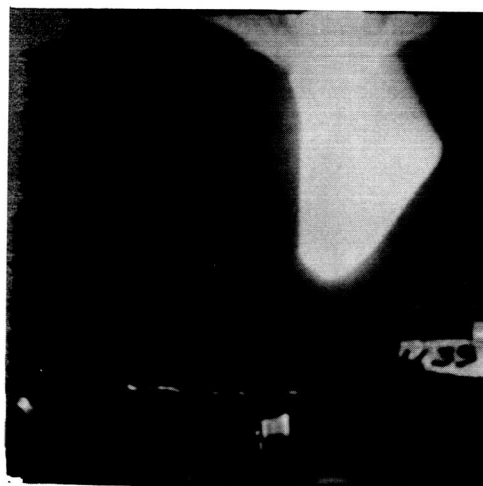
Figure 21.- Great Lakes type R graphite model.



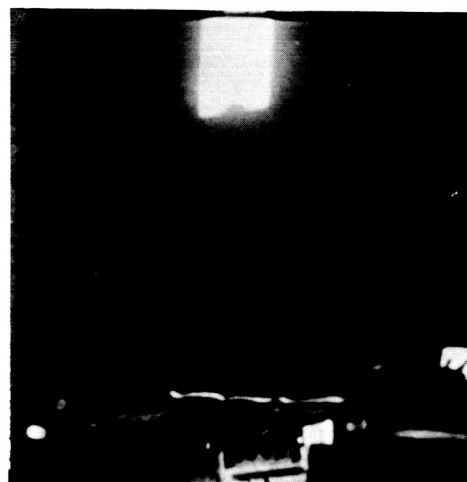
0 seconds



10 seconds



22 seconds

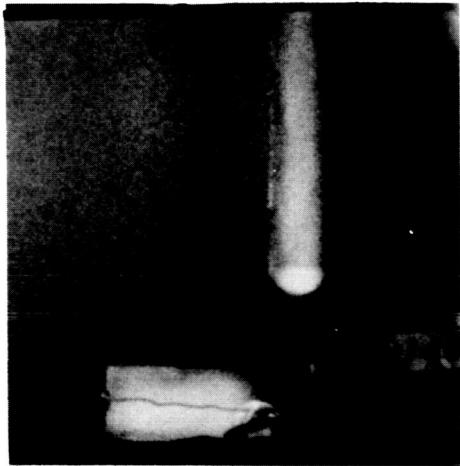


22.5 seconds

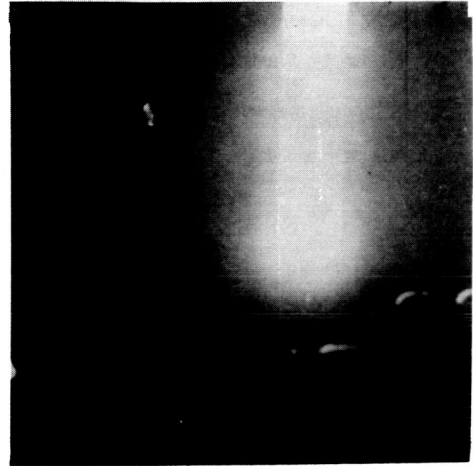
(b) During the test.

L-59-6444

Figure 21.- Continued.



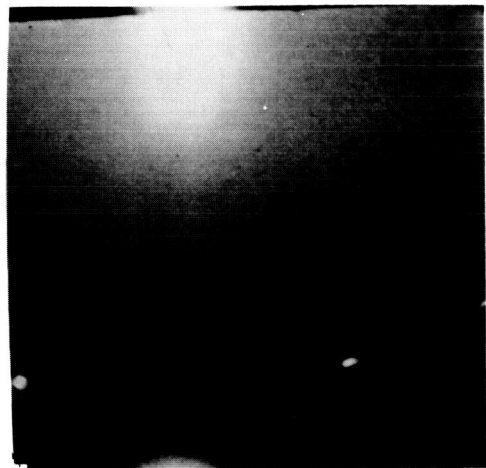
0 seconds



10 seconds



20 seconds

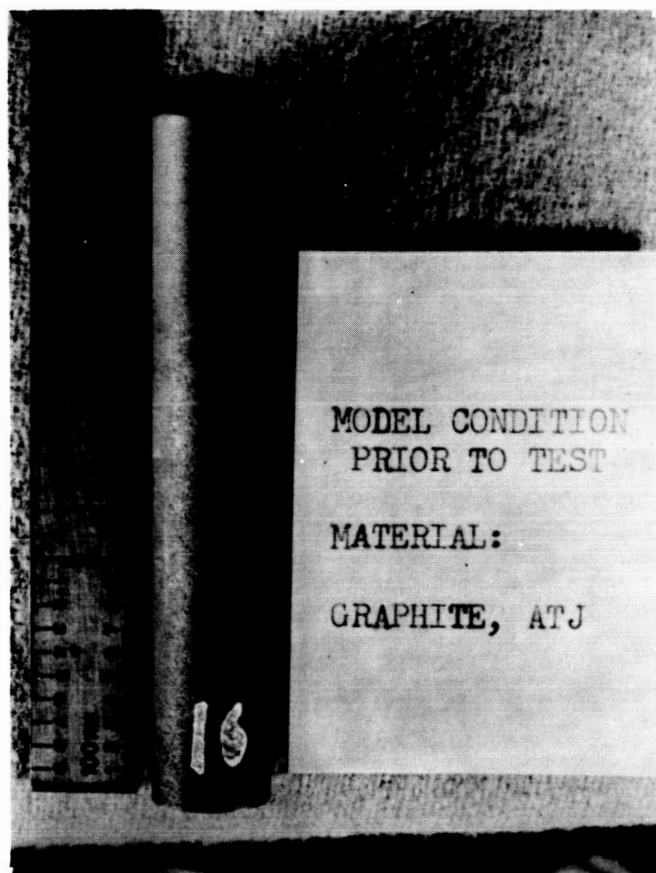


27 seconds

(c) During a duplicate test.

L-59-6445

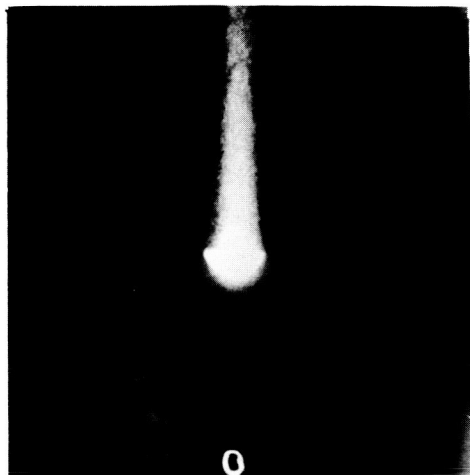
Figure 21.- Concluded.



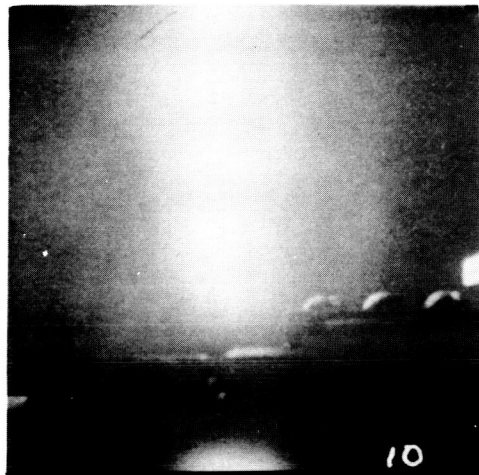
(a) Before the test.

L-59-6446

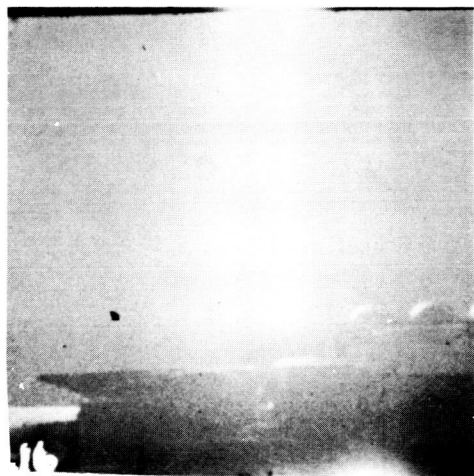
Figure 22.- ATJ graphite model.



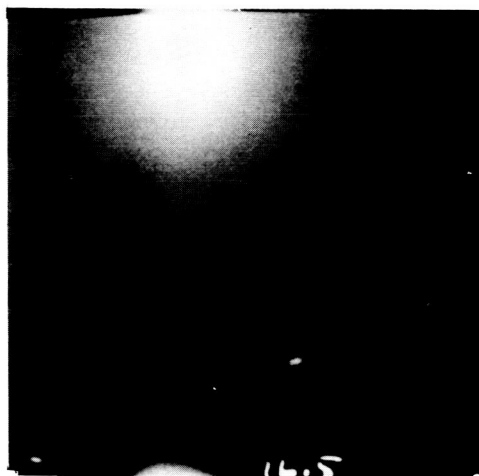
0 seconds



10 seconds



16 seconds

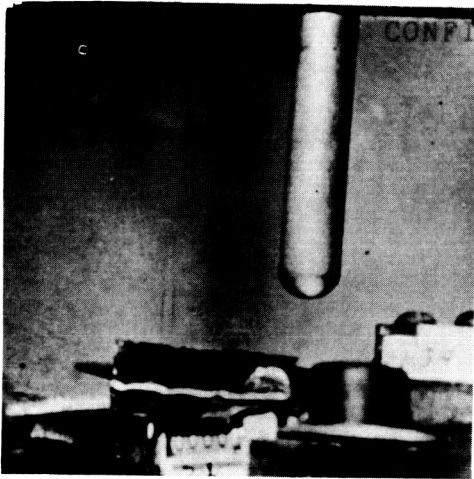


16.5 seconds

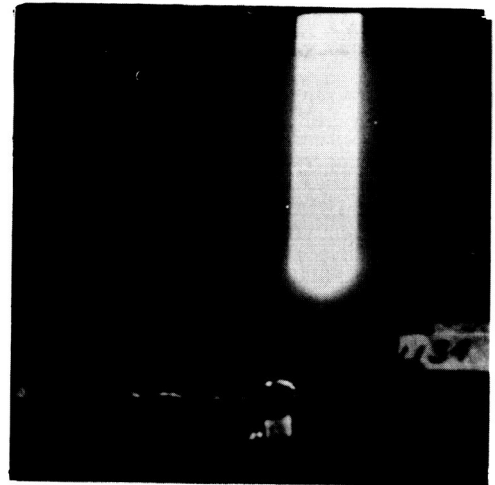
(b) During the test.

L-59-6447

Figure 22.- Continued.



0 seconds



10 seconds



16 seconds

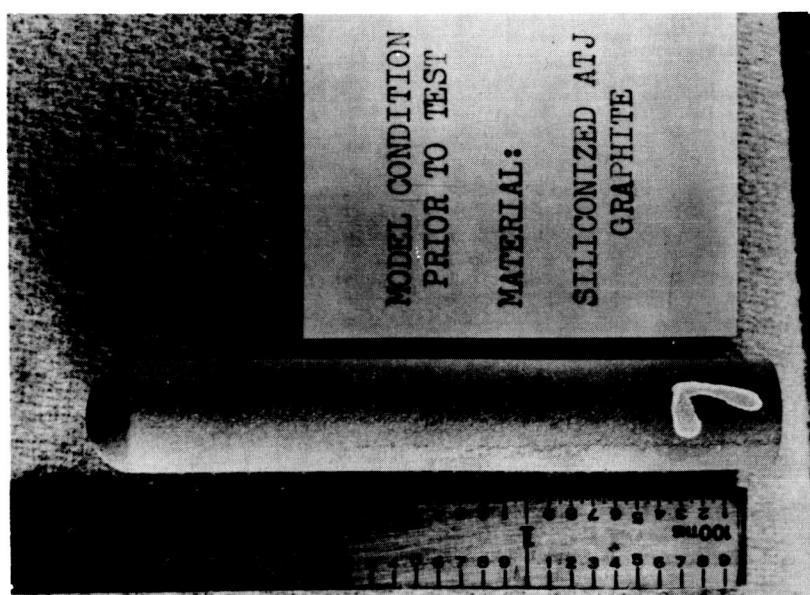
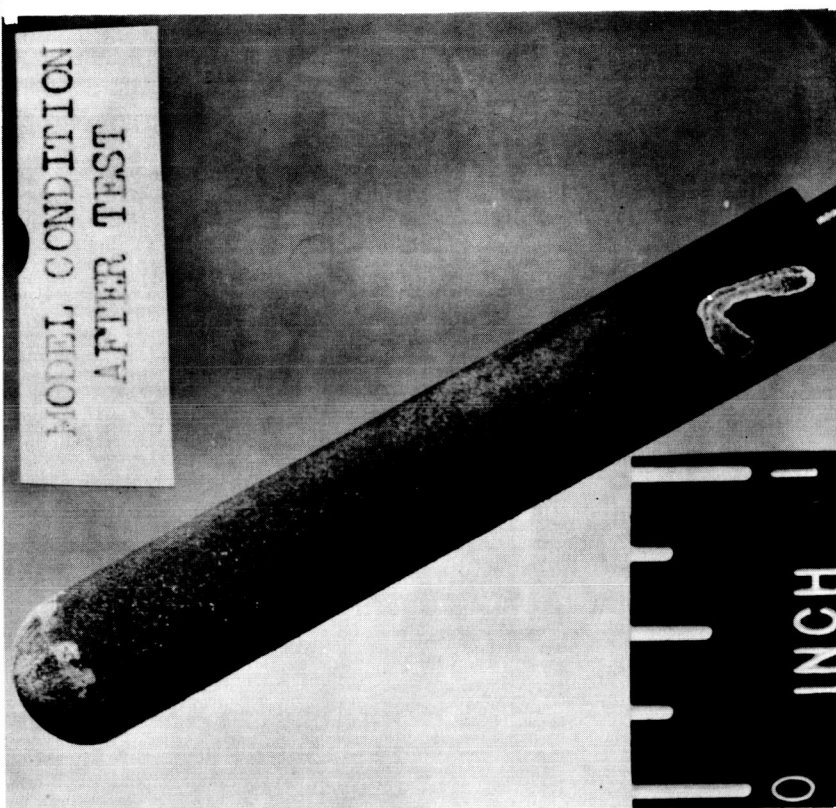


16.5 seconds

(c) During a duplicate test.

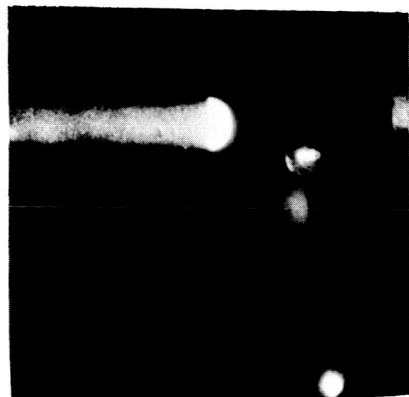
L-59-6448

Figure 22.- Concluded.

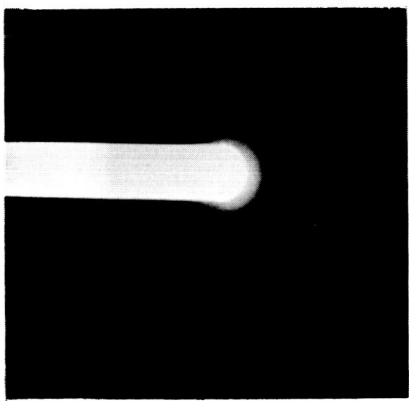


(a) Before and after the test. L-59-6449

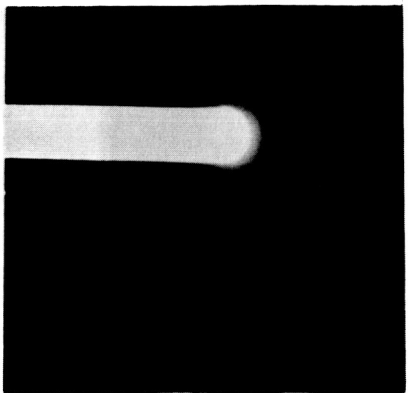
Figure 23.- Siliconized ATJ graphite models.



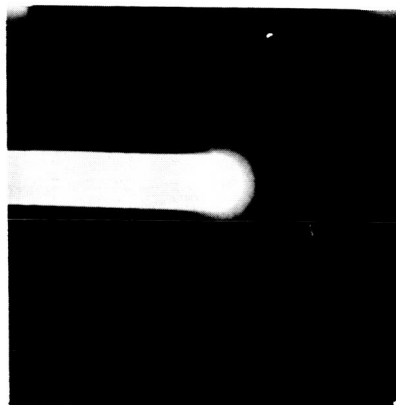
0 seconds



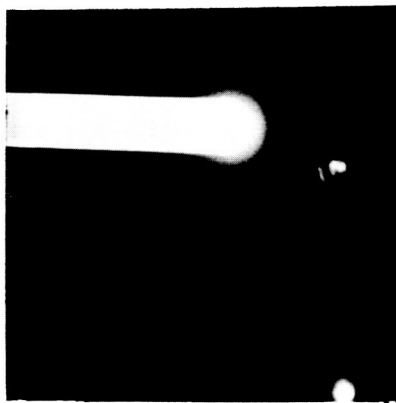
10 seconds



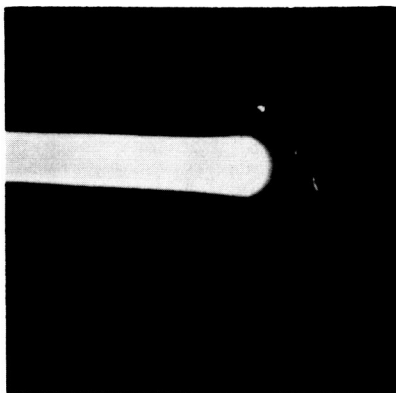
20 seconds



30 seconds



40 seconds

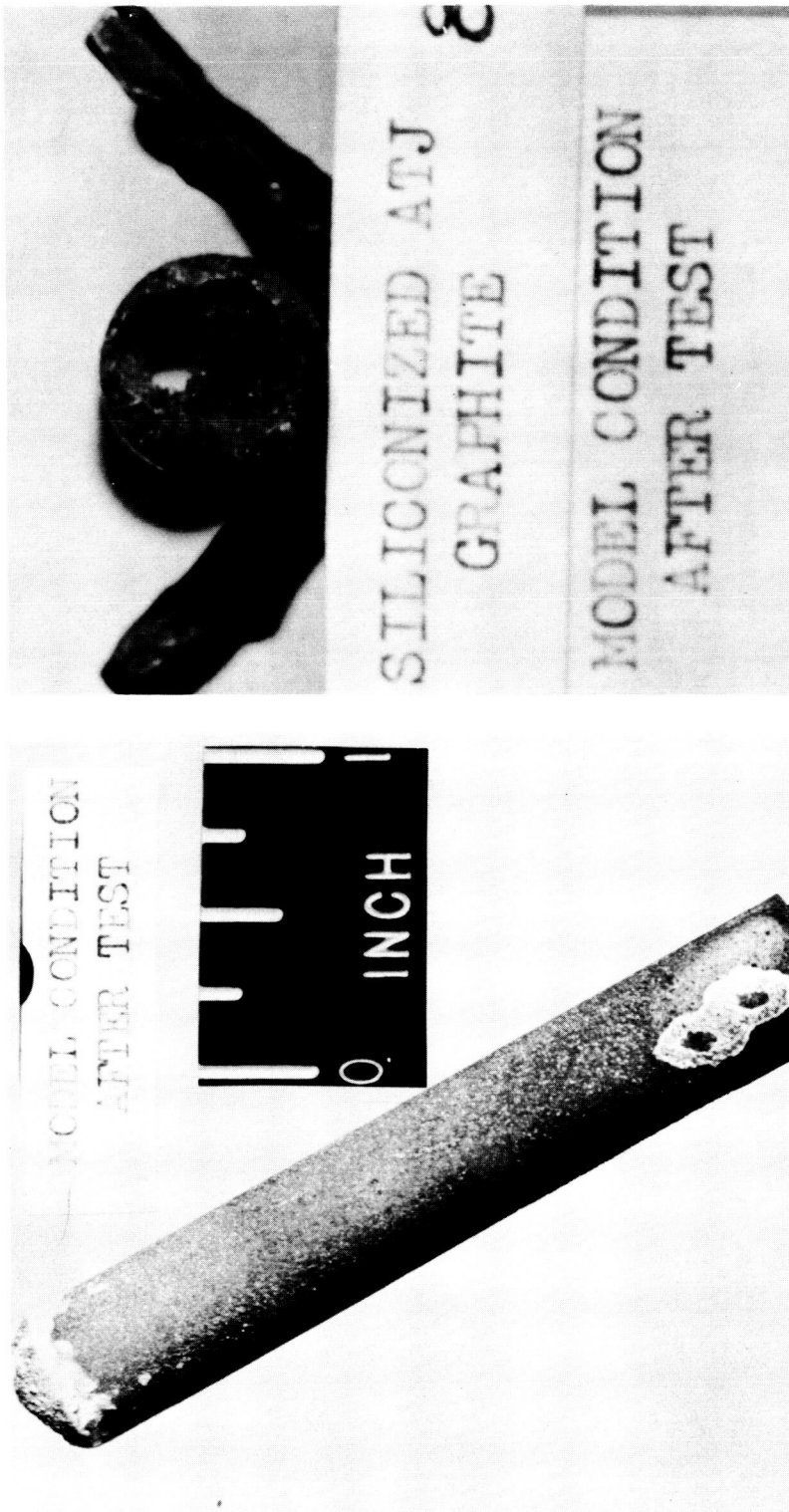


60 seconds

(b) During the test.

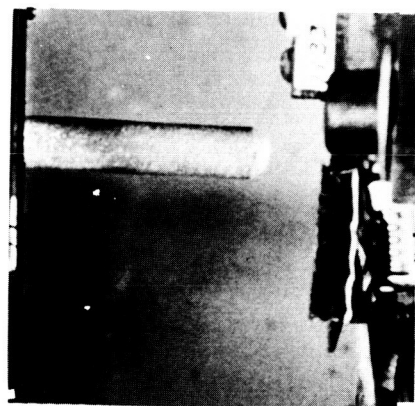
L-59-6450

Figure 23.- Continued.



Front view of model
 (c) Duplicate model after the test. L-59-6451

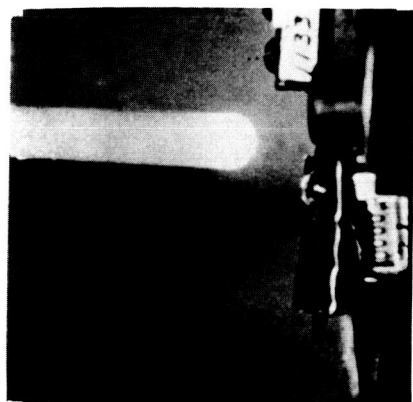
Figure 23.- Continued.



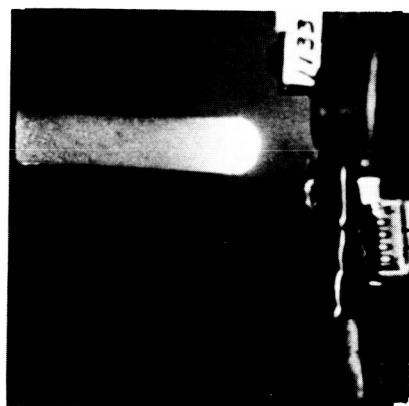
0 seconds



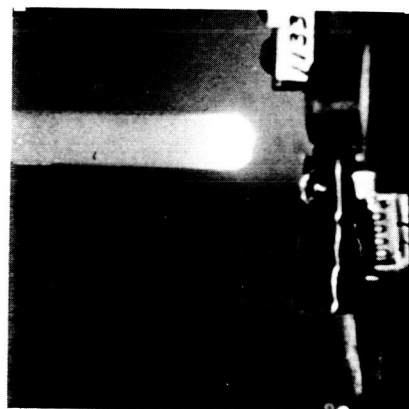
10 seconds



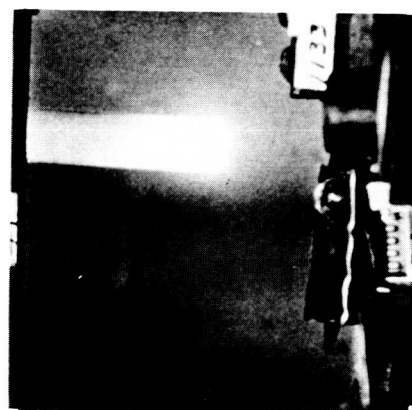
30 seconds



40 seconds



50 seconds

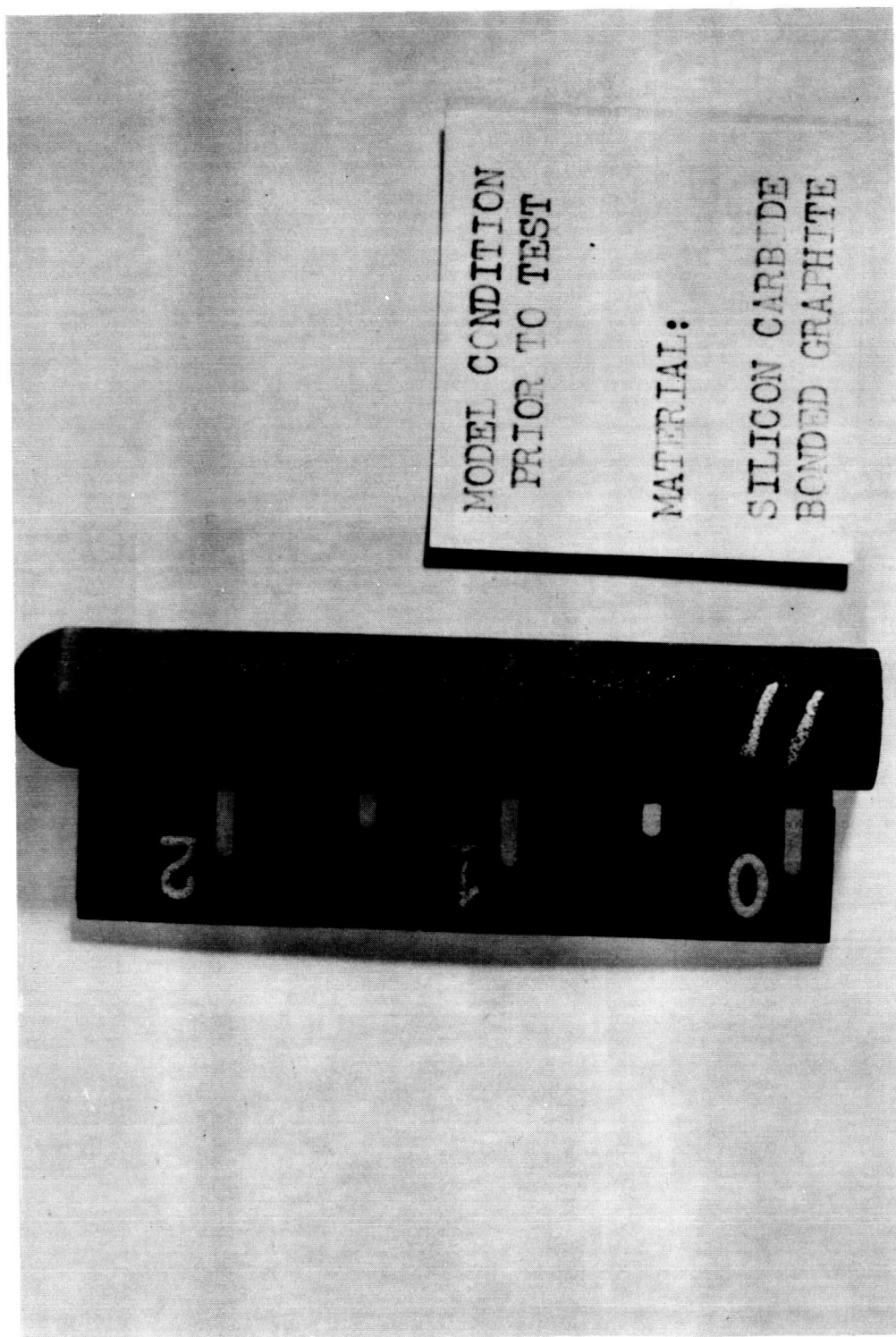


60 seconds

(a) Duplicate model during the test.

L-59-6452

Figure 23.- Concluded.



(a) Before the test. I-58-1015a

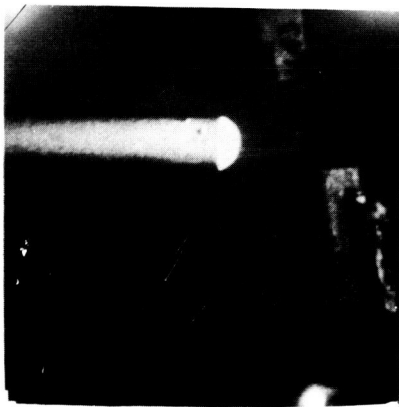
Figure 24.- Silicon carbide bonded graphite model.



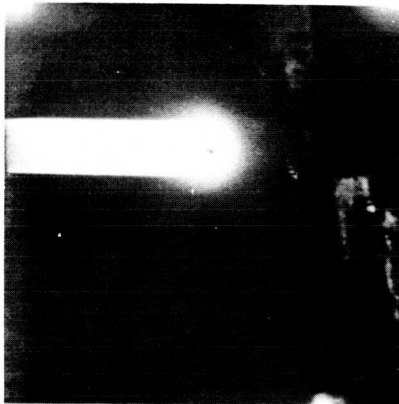
(b) After the test.

L-59-250

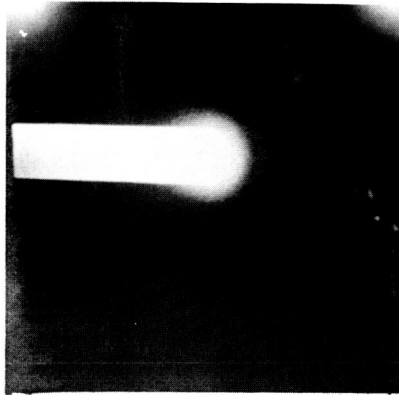
Figure 24.- Continued.



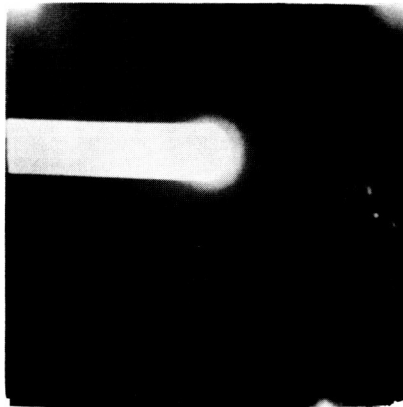
0 seconds



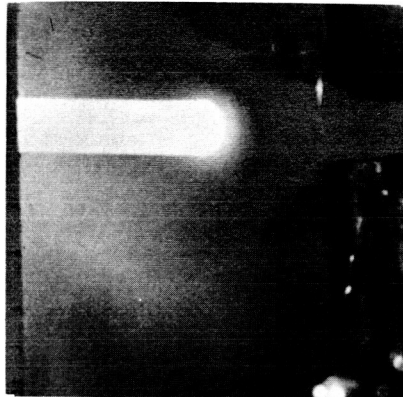
10 seconds



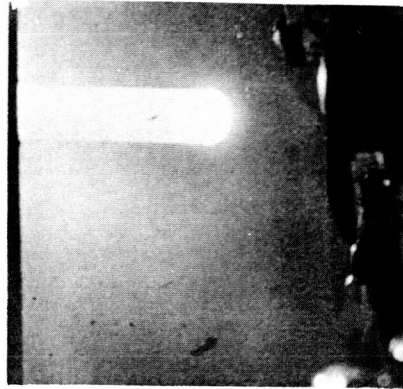
20 seconds



40 seconds



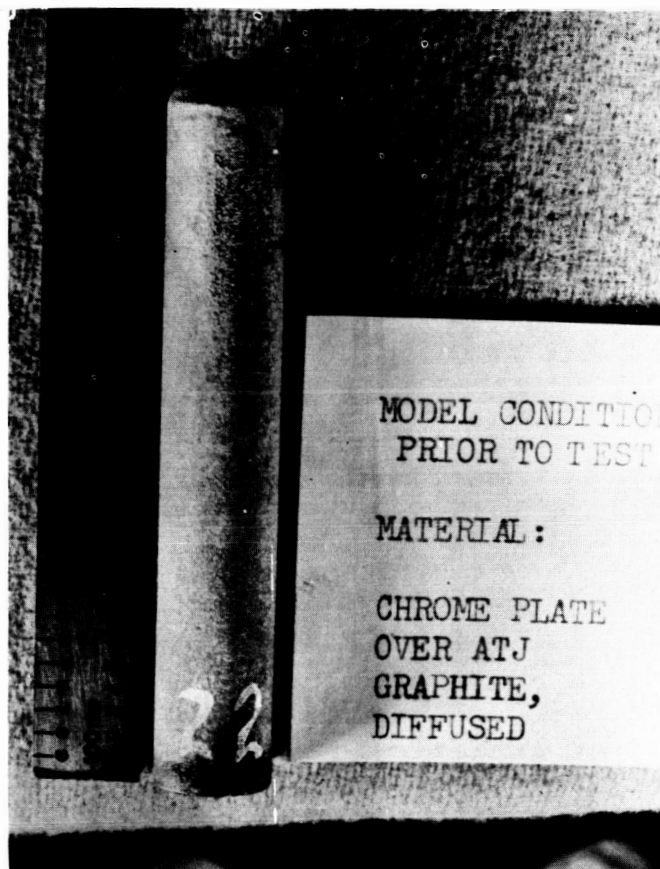
50 seconds



60 seconds

(c) During the test. L-59-6453

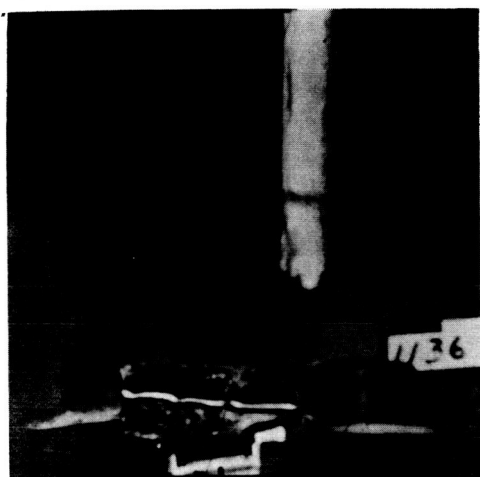
Figure 24.- Concluded.



(a) Before the test.

L-59-6454

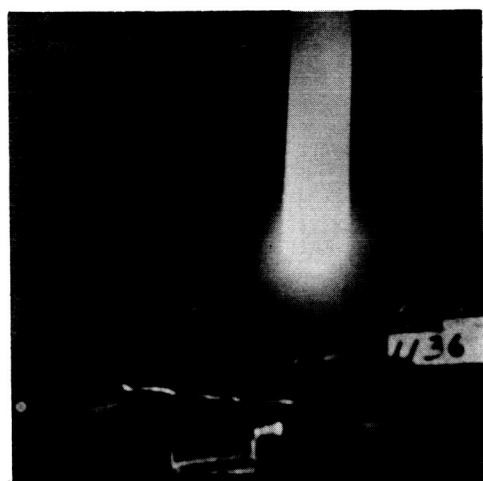
Figure 25.- Chrome plated ATJ graphite model.



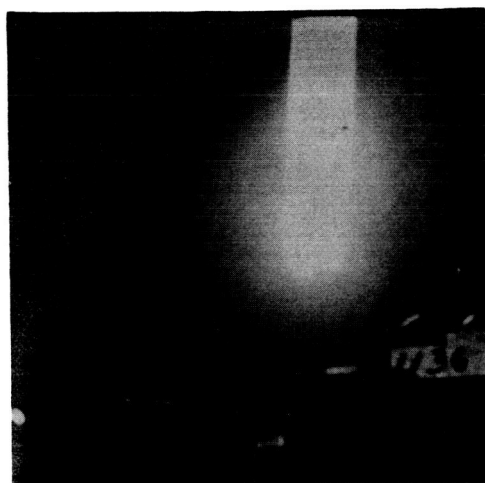
0 seconds



10 seconds



20 seconds

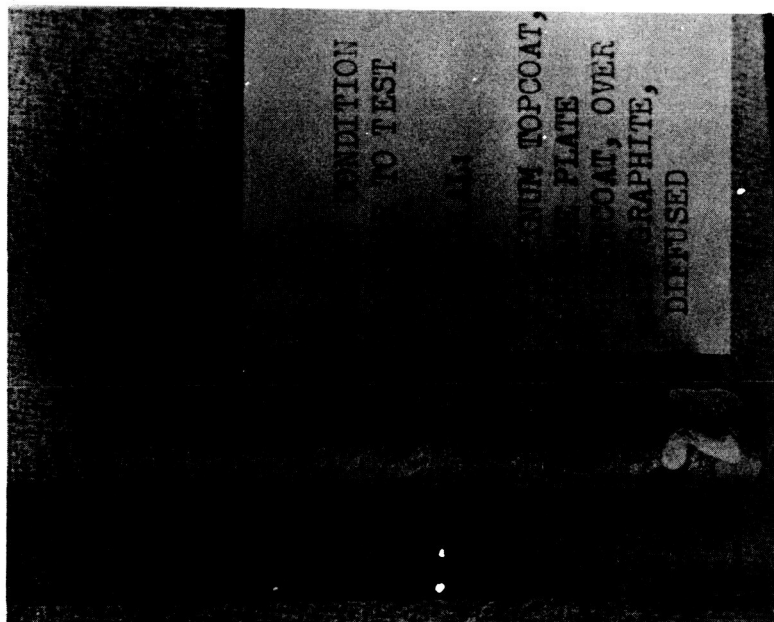


23.5 seconds

(b) During the test.

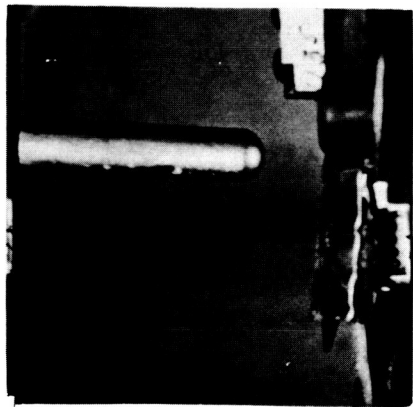
L-59-6455

Figure 25.- Concluded.

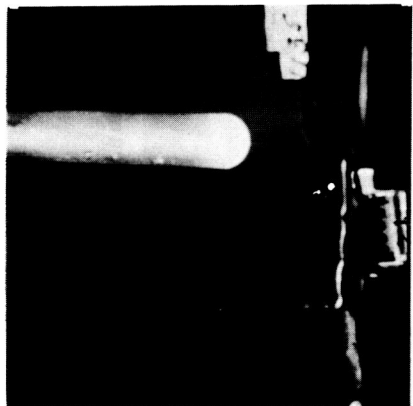


(a) Before and after the test. L-59-6456

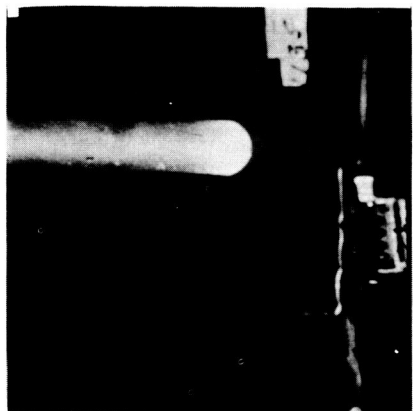
Figure 26.- Platinum chrome plated ATJ graphite model.



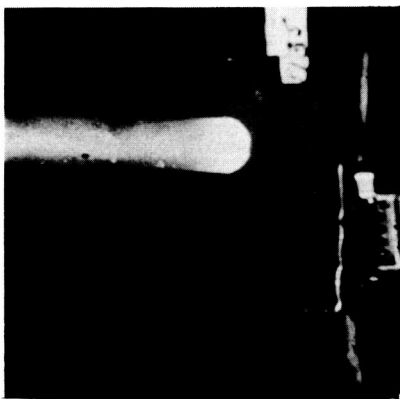
0 seconds



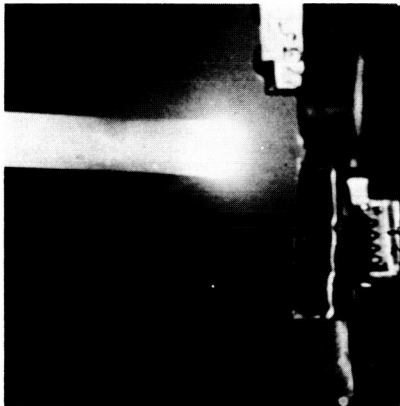
10 seconds



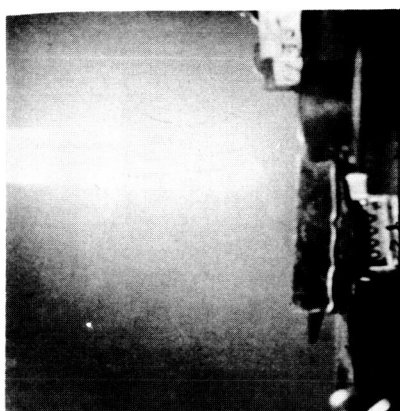
30 seconds



40 seconds



50 seconds

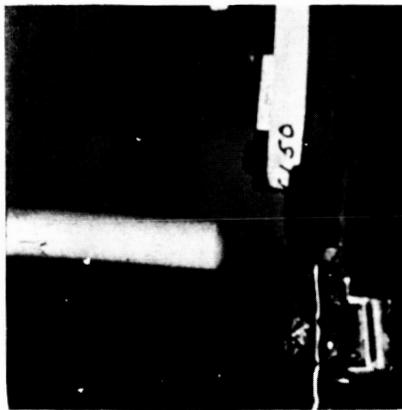


58 seconds

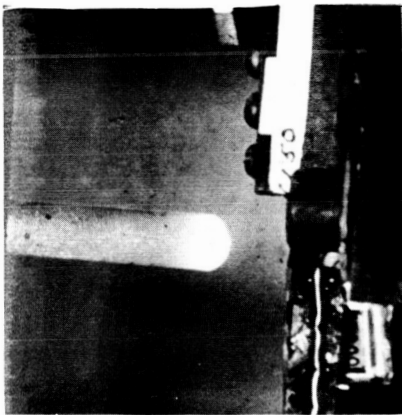
(b) During the test.

I-59-6457

Figure 26.- Concluded.



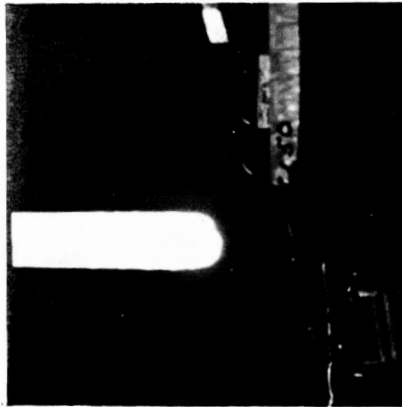
0 seconds



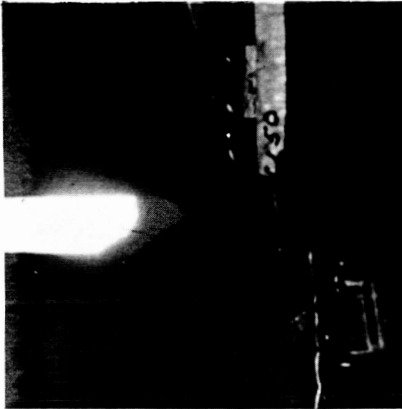
10 seconds



20 seconds

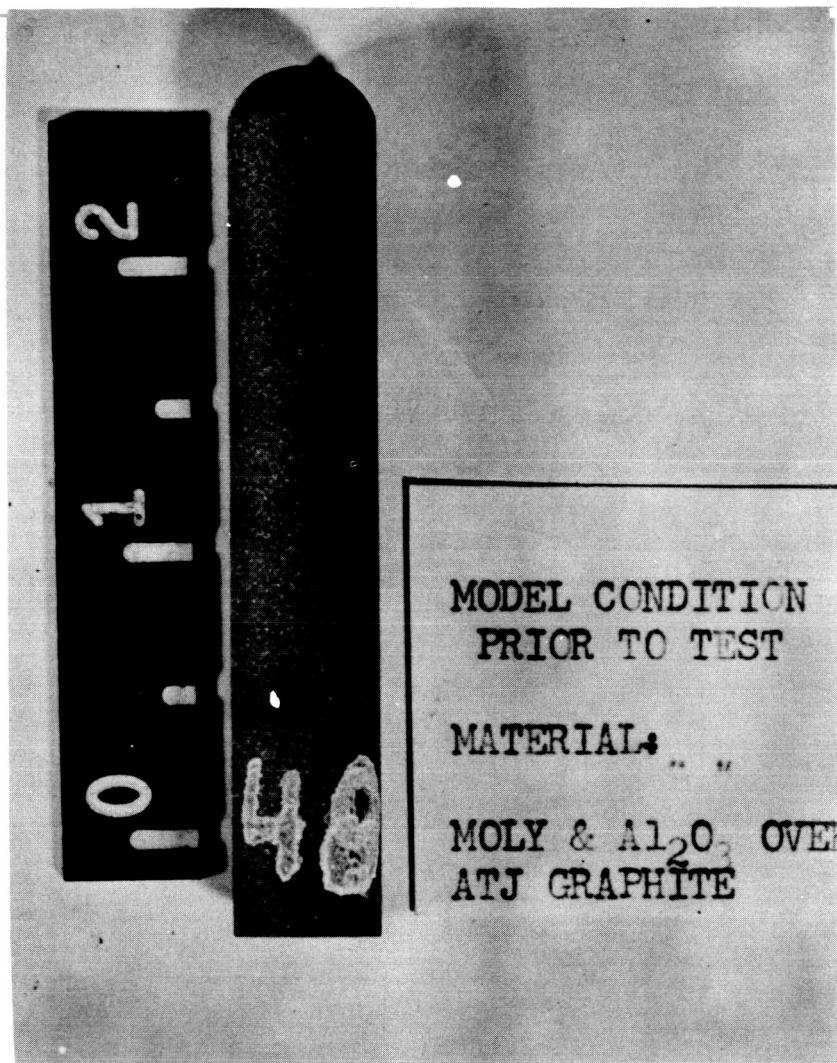


30 seconds



33 seconds

Figure 27.- Zirconia molybdenum laminate over ATJ graphite model at various times during the test.

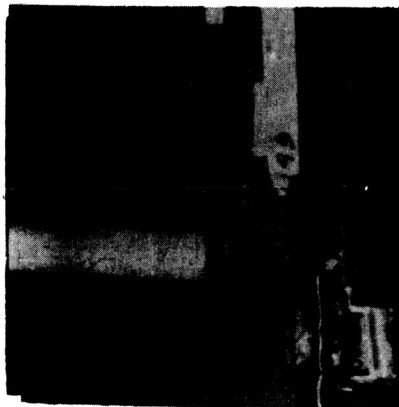


(a) Before the test.

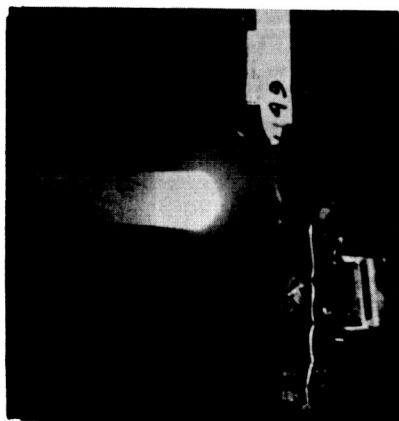
L-59-6459

Figure 28.- Alumina-molybdenum laminate over ATJ graphite model.

L-725



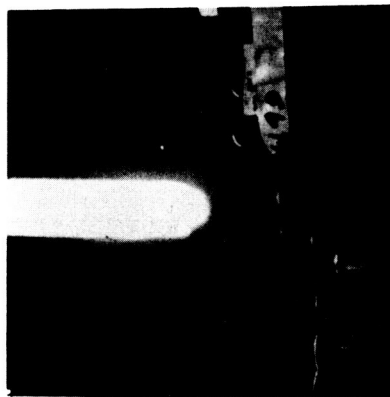
0 seconds



10 seconds



20 seconds



30 seconds



32 seconds

L-59-6460

(b) During the test.

Figure 28.- Concluded.